TEXT IS FLY

THE HEAVENS

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ILLUSTRATED

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CONTENTS

FOURTH LESSON

FIFTH LESSON

SIXTH LESSON

SEVENTH LESSON

FOURTEENTH LESSON

FIFTEENTH LESSON

SIXTEENTH LESSON

TWENTY-FIFTH LESSON

ILLUSTRATIONS

LIST OF FULL-PAGE ILLUSTRATIONS

THE HEAVENS

FIRST LESSON

GEOMETRY

Surveying the sky by Geometry, 1.—The angle, 2.—Perpendicular and oblique, 3.—Acute angle, obtuse angle, and right angle, 3.—Circumference, radius, diameter, arc, 4.—Graduation of the circumference, 4.—The protractor, 5.—Measuring an angle, 5.—The theodolite, 5.—Sum of the external angles of a polygon, 6.—Experimental proof and theoretical proof, 6.—The triangle, 7.—Sum of its three angles, 7.—Experiment and demonstration, 7.—Different species of triangles, 8.—Sum of the two acute angles of a triangle, 8. (*The numbers represent paragraphs.*)

1. IF we were to judge by appearances, we should regard the firmament as a great vault, luminous and of a blue colour in the daytime, black at night, and strewn with the gold dust of stars. But science teaches us that these appearances are deceptive, it tells us that no celestial ceiling curves around us. Space is free at our feet as well as over our heads, on the right as well as on the left ; it is peopled with legions of enormous stars where our ignorance only sees brilliant points, and it stretches in every direction towards the horizons of which only God knows the centre and the limit, and which His gaze alone can compass. Amidst these immensities floats the Earth, insignificant in the total, like a mote in a sunbeam. In order to gain information concerning the abysses of the Universe, and to find out the distances

of the various heavenly bodies and their real size, our reason seeks the aid of Geometry. It is a difficult science, I admit, which interests young brains but little, but you may rest assured that I shall not tire you with learned theorems which might be beyond your comprehension. A few very elementary explanations will suffice. If the dryness of certain geometrical paragraphs repels you, sit tight and muster your courage, for the matter dealt with will be worth while: To measure the sky, to survey the Universe. Think of it, children—is it not worth a few minutes' attention? Well then, here goes!

2. What we call an angle is the more or less great opening left between two straight lines which intersect. The point where the two lines meet is called the "apex" of the angle, and the two lines themselves are called the sides of the angle. Thus, for example, the two straight lines AB and AC (Fig. 1) meet at the point A, separating from each other and opening out to leave a space between them which we call an angle.

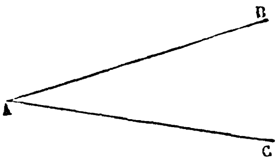


FIG. 1.

The point A is the apex of the angle, while AB and AC are the sides. In order to indicate the angle we use the three letters denoting the sides, but always put the apex in the middle. Thus we speak and write indifferently of the angle BAC or the angle CAB, but we cannot talk of the angle ABC. When there is no possible uncertainty concerning the angle meant, it suffices to mention the letter at the apex. It can also be designated by means of a letter or number placed inside the opening.

The straight line has no end, for it can always be considered produced or prolonged. The value of an

angle does not, therefore, depend on the length of its sides, which we can make as long or as short as we please without in any way changing their inclination. The angle, in fact, only means the inclination. Thus (in Fig. 2) two angles, BAC and HDK, are equal when the inclinations of their sides are equal, whatever may be the length of the sides. After all, there is nothing to hinder us imagining the sides of the angle BAC made as long as those of the angle HDK, or even longer, for a straight line has no end, and every portion of the straight line traced in our diagrams must be considered capable of being prolonged indefinitely.

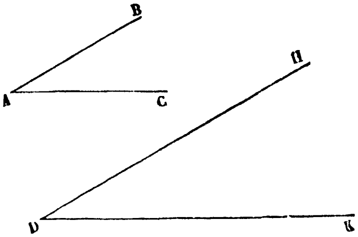


FIG. 2.

3. Let a straight line DC be met by another line BA (Fig. 3). This gives us two angles—a small one, BAC, and a larger one, DAB. The small one is called an acute angle, and the large one an obtuse angle. Let us imagine that BA gets more and more upright. The acute angle will increase and the obtuse angle will diminish. There will come a moment when the straight line BA will be perfectly upright, and will not lean more to one side than to the other on the straight line DC as shown in Fig. 4. At that moment the two angles BAC and BAD will be equal. We then say that BA is perpendicular to DC,

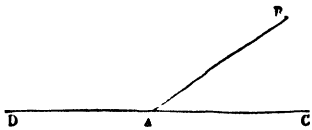


FIG. 3.

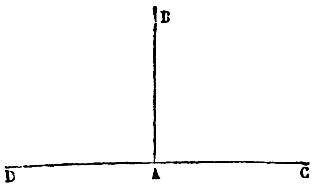


FIG. 4.

and the two equal angles thus formed are called right angles. Every straight line which is not perpendicular is said to be "oblique."

In Fig. 3 it is evident that BA can lean more or less towards DC, and can be more or less oblique, and this changes the value of the acute angle and of the neighbouring obtuse angle. We can therefore have a large number of acute angles of different values and also a large number of obtuse angles, but there is only one right angle, for there is only one position in which the straight line AB does not lean more to one side than another with respect to DC. To sum up: the right angle has an invariable value, while the acute angle varies in amount, but is always less than a right angle; the obtuse angle also varies, but is always greater than a right angle.

4. When describing a curve with compasses we call the line described by the moving point of the compasses the "circumference," and we call the fixed point the centre. The circumference is sometimes called the "circle," but it is better to reserve that word for the area enclosed in the circumference. Every straight line, such as OA (Fig. 5), drawn from the centre to the circumference, is called a "radius." There are, of course, an infinite number of radii, and they are all equal, since each of them measures the distance between the points of the compass describing the circle. Every straight line BC passing through the centre and limited at each end by the circumference is called a "diameter." A diameter is double the length of the radius, and

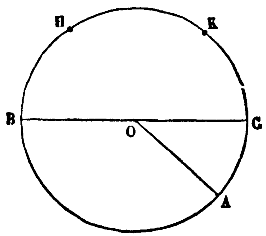


FIG. 5.

divides the circumference into two equal parts. Finally, any portion of the circumference, such as HK, is called an "arc" of the circle.

It is agreed to divide every circumference into 360 equal parts, called degrees; each degree into 60 equal parts, called minutes; and each minute into 60 equal parts, called seconds.[1] Thus, the whole circumference contains 360 degrees, or 21,600 minutes, or 129,600 seconds.

The degrees of a circle are not measured in inches or in metric measures. They only indicate what proportion of the circumference is contained in the arc. Thus, when we say that an arc of a circle has 90 degrees it simply means that the arc contains 90 times the 360th part of the circumference, or that it is one-quarter of that circumference, without implying anything concerning its length. The arc can be larger or smaller according to the area of the circle to which it belongs, and yet have the same value in degrees. If we describe round the centre O three circles (Fig. 6), and draw through the centre two straight lines AB and DC, intersecting at right angles, and perpendicular to each other, each of the three circumferences will be divided into four equal portions, and the three arcs AC, HK, and VP, though very different in length, will have the

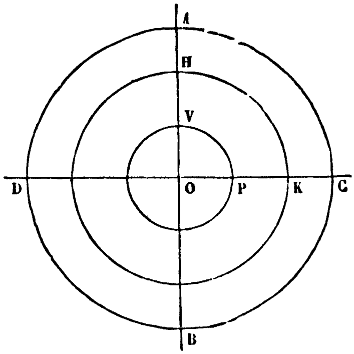


FIG. 6.

[1] These minutes and seconds of an arc must not be confused with minutes and seconds of time. In spite of their similar denomination they have nothing whatever in common.

same value in degrees. Each will contain 90 degrees, since each of them is a quarter of the corresponding circumference.

5. A "protractor" is a transparent semi-circle of horn or celluloid divided into degrees. A diameter is engraved at the base, and from one of the extremities of this diameter degrees are marked off from zero to 180, which is half the entire circumference, that is to say, half 360 degrees. The protractor is used for measuring angles on paper.

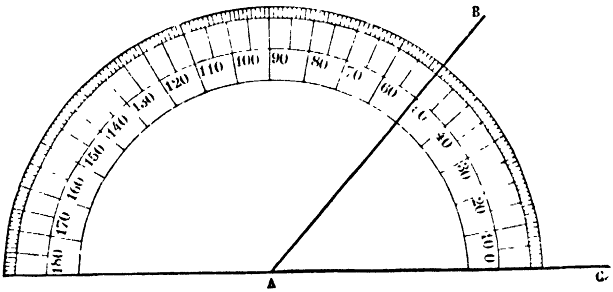


FIG. 7.

Thus, in order to obtain the value of the angle BAC (Fig. 7) the protractor is laid on the angle so that the centre of the instrument is placed at the apex A of the angle, and that the diameter coincides with one of the sides, such as AC. We then read off the division at which the other side cuts the circle. In the diagram this is the division 50. A right angle always contains 90 degrees, or a quarter of the circumference. An acute angle is less than 90 degrees, and an obtuse angle more than 90 degrees.

For astronomical, or even surveying, operations very large brass protractors are used, mounted on tripods and

called theodolites (Fig. 8). On these instruments it is possible to read down to minutes of arc, and even seconds, when the dimensions of the graduated circle are sufficient. Theodolites are provided with two telescopes, one a fixed one which looks along the diameter of the instrument, and the other movable round a pivot placed at the centre. To measure an angle in space the theodolite is placed at the apex of that angle, the fixed telescope is pointed in the direction of one of the sides, and finally the movable telescope is directed along

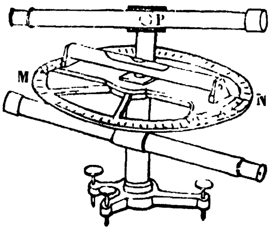


FIG. 8.

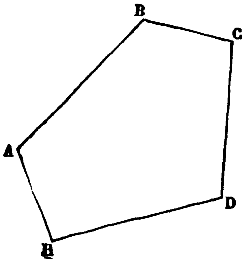


FIG. 9.

the other side. It then suffices to read on the rim of the instrument the number of degrees enclosed.

6. Every figure formed by straight lines meeting each other in succession is called a "polygon." If the polygon has only three sides it is called a triangle; if it has four, five, six, or more sides it is called a quadrangle, pentagon, hexagon, etc.

A polygon can take an infinite variety of forms; it may contain any number of sides, it may be large or small, it may be regular or irregular. Yet, among all these variations there is something in the geometrical figure which never changes, as we shall see.

Let us trace on the paper any sort of polygon that occurs to us, such as the polygon ABCDH (Fig. 9). If we

produce the various sides of the polygon always in the same direction, as shown in Fig. 10, we obtain a series of angles, 1, 2, 3, 4, 5, which are called the external angles of the polygon. Let us imagine that these angles are all cut out with scissors, and are then placed side by side round the same point (Fig. 11). Then it will always happen, whatever the configuration of the polygon and the number of its sides, that these angles will make a complete turn and will fall into place so that the last of them will exactly fill the space between the first and the last but one. If, now, we draw a circle round the point A (Fig. 11), it is clear that the aggregate of these angles thus grouped round the point without a gap comprises the whole of the circumference. Thus the sum of the external angles of any polygon always amounts to 360 degrees.[1]

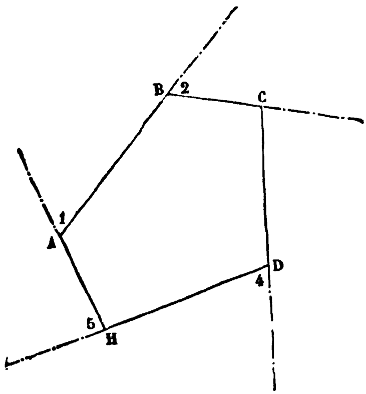


FIG. 10.

This is certainly a very curious property, which I ask you very earnestly to verify by cutting out and assembling round a common point the external angles of different polygons which you will draw on paper. This property might have been foreseen with a little reflection. You

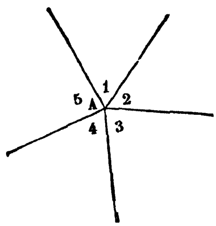


FIG. 11.

[1] Polygons with re-entrant angles must be excluded, as in that case the law is different.

will notice, in fact (Fig. 10), that the external angles 1, 2, 3, 4, 5 of the polygon each open towards a special region of the surface plane on which the figure is traced, and comprise in their aggregate all imaginable directions across that surface. If, therefore, they are grouped round a common point they must include every possible direction and thus make a complete turn.

7. The triangle is the simplest polygon. It has only three sides. In spite of its simplicity it has the same general property as the most complicated polygons, that is to say, the sum of its external angles amounts to 360 degrees. From this we may deduce a property of the triangle which may be very useful to us later.

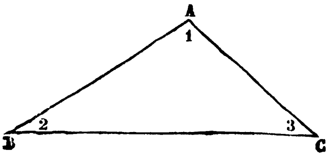


FIG. 12.

Take the triangle ABC (Fig. 12). We want to prove that the angles 1, 2, 3 together amount to 180 degrees. To do this let us produce the sides so as to form the external angles 4, 5, and 6 (Fig. 13). It is clear that the angles 1 and 4 together make 180 degrees, for if we put a protractor so that its diameter coincides with the

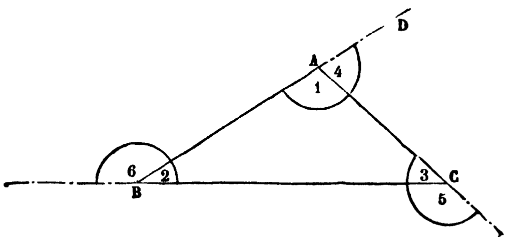


FIG. 13.

straight line BAD, and its centre with the point A, the two angles in question would comprise the semi-circle

which constitutes the protractor. This is shown by the semi-circle traced on the diagram. Similarly the angles 3 and 5 amount to 180 degrees, and so do the angles 2 and 6. This gives for the angles 1, 2, 3, 4, 5, and 6 an aggregate amounting to three times 180 degrees. If from this aggregate we subtract the sum of the external angles 4, 5, and 6, which equal 360 degrees, or twice 180 degrees, we obtain for the sum of the angles 1, 2, and 3 just 180 degrees. Hence, as stated above, in every triangle the sum of the three angles equals 180 degrees.

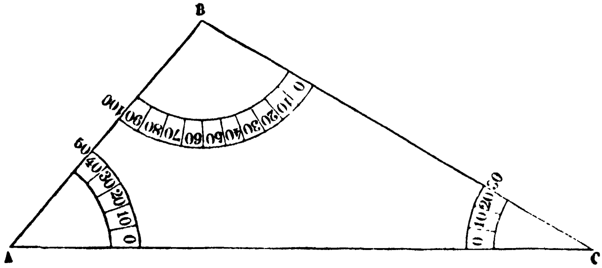


FIG. 14.

If you find any difficulty in understanding my demonstration make the following experiment. Trace on paper any triangle such as ABC (Fig. 14). Measure the three angles with a protractor. The angle A is found to be 50 degrees, the angle B 100 degrees, and the angle C 30 degrees. These values, 50, 100, 30, when added together amount to just 180 degrees. Well, you will always, in any triangle without exception, arrive at the sum of 180 degrees, provided your measures are correctly made, which is not without some difficulty, especially with a simple protractor.

8. Among all the forms which a triangle can take we must specially consider three.

If the three sides are equal, as in Fig. 15, the triangle is equilateral. In that case the three angles are equal to each other, and each is one-third of 180 degrees, or 60 degrees.

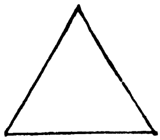


FIG. 15.

If only two sides of the triangle are equal it is called an "isosceles" triangle (Fig. 16). In this case the angles opposed to the two equal sides are of the same value.

If the triangle has a right angle it is called a rectangular triangle, such as the triangle ABC (Fig. 17). Its angle A, formed by AB and AC perpendicular to each other, is a right angle, and therefore amounts to 90 degrees. Then the other two angles B and C amount to 90 degrees in the aggregate, in order to make the total 180 degrees. Let us remember for the future that the sum of the two acute angles of a rectangular triangle is equal to 90 degrees. Let us note, finally, that the side BC opposed to the right angle is called the "hypotenuse" of the rectangular triangle.

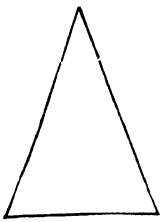


FIG. 16.

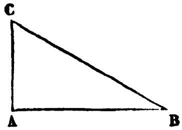


FIG. 17.

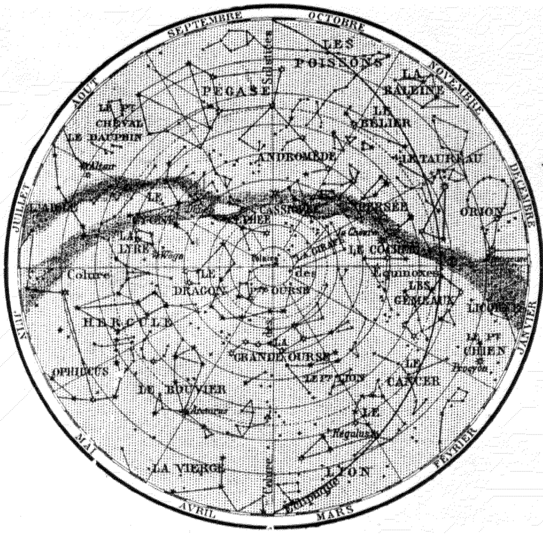
Let us here, for a moment, end our modest geometrical studies. What shall we do with these very elementary notions? We shall measure the Earth!

SECOND LESSON

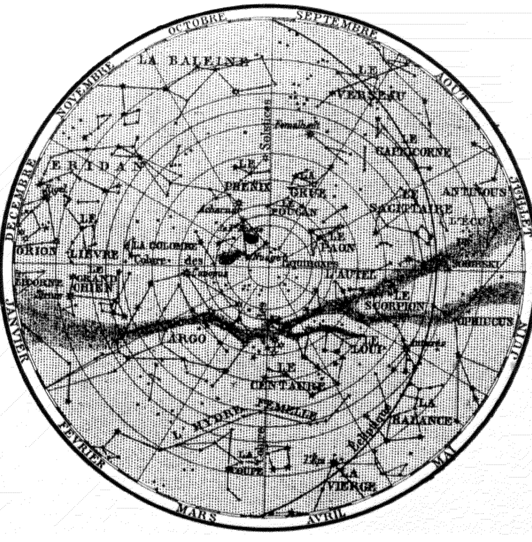
SURVEYING THE EARTH

The roundness of the Earth, the horizon, 1.—The circumference of a clock, 2.—Measuring the circumference of the Earth, 3, 4 and 5. —The plumb-line, 4.—Cutting an apple; Great circles and small circles of a sphere, 6.—The population of France holding hands, 7.—Travelling on foot, 7.—The cloud which leaps from hill to hill, 7.—The highest mountain of the Earth and a grain of sand, 8.—Brushing on the oceans, 8.—The atmosphere like the down on the peach, 8.—The Earth's roundness not marred by inequalities of the surface, 9.—Numerical values concerning the Earth, 9.

1. THE Earth is an enormous ball floating in celestial space without any support. Let us recall the simplest among the various proofs that it is round. In a flat country our view of the Earth is limited by a circular line, which we call the "horizon," whatever may be our elevation above the ground. It is the line where the plain and the sky seem to meet. On the sea, in the absence of the various irregularities, rocks, hills and mountains, which generally obscure the view, the rounded form of the horizon is very striking. In vain does the ship sail forward for days, weeks, months, the traveller is always at the centre of a monotonous circle which limits his view. He always sees, along an exactly circular line, the blue of the water mingling with the blue of the sky. Is the appearance of the horizon caused by the feebleness of our view, which cannot distinguish



A. Stars in the Northern Hemisphere.



B. Stars in the Southern Hemisphere.

[*To face p.* 12.

objects beyond a certain distance? No, for then the use of a telescope would immediately make the horizon recede. But nothing of the kind happens; the rounded line which limits the naked eye also limits the range of the best instruments. The horizon is insurmountable, it is therefore formed by the apparent contour of the terrestrial Globe, by the line of separation between the visible and invisible parts of the Earth, which is curved everywhere, and what prevents us seeing the objects situated beyond certain limits is not the feebleness of vision, it is the curvature of the Globe. The conclusion is quite natural: if the expanse of Earth embraced by the eye is always round, the Earth itself is round in its entirety.

2. Once the roundness of the Earth is recognised, a great question presents itself: What is the circumference of the enormous ball? What is its value in miles? I could simply tell you that the Earth is 10,000 leagues, or 24,000 miles round, but I hope to do better and to make you understand by what ingenious measures the Earth has been measured. In order to measure a length you only know one means, that of carrying a foot-rule and applying it as many times as it will fit to the length to be measured. This means is, of course, impracticable when it comes to measuring the circuit of the terrestrial Globe. To think of taking the foot-rule or yard-stick over continents full of mountains and over the tempestuous surfaces of the sea would be folly, human force would not suffice for the task. Then what shall we do? We shall use Geometry, which laughs at such difficulties.

If it were proposed to measure the circumference of a clock face you would no doubt proceed as follows. You would wind a string exactly round the face, and you would then stretch out that string and measure it

in inches, and the result would give you the required length. That would be a direct and excellent procedure, but it could not be applied to the Earth, which is immensely greater. There is a more indirect and simple method which we can use for measuring the face of the clock. In every clock the clock face is divided into 12 equal parts, corresponding to the 12 hours of the day. Let us measure one of these portions; let us measure, for instance, the distance which the hand travels from 12 to 1 o'clock. Is it not true that by multiplying the length so obtained by twelve we shall obtain the entire circumference of the clock face? That is something like the process which is adopted to measure the circuit of the Earth. As we cannot measure the terrestrial circumference in its whole extent we measure a part of it. If we then succeed in ascertaining how many times that portion is contained in the whole, we have solved the question. Unfortunately the terrestrial Globe has no equal divisions traced on its surface, like a clock face, so that the difficulty seems to remain. Who will tell us how many times the distance we have laboriously measured is contained in the whole circuit? Geometry will tell us, as we shall see.

3. In a vast and regular plain, the higher we rise above the ground the greater will be the extent of the horizon. Let our point of observation be a tower, for example. From the top of this observatory let us observe with a telescope at what point of the horizon the length of our vision is limited by the curvature of the Earth. Let us determine, in fact, the position of the point C (Fig. 18). Then by the ordinary process of surveying, that is to say, by applying the surveyor's chain time after time, you measure the distance between the foot of the tower

and the farthest point seen on the horizon. In other words, you measure the arc BC. You might find, for instance, 55,000 yards. You will realise that that is not an easy operation, but with care and time you may succeed. Then, the length of the terrestrial arc BC is known. What, now, do we require for measuring the whole circuit of the Earth? We require to know how many times that arc is contained in the entire circumference; for if we know, for instance, that it is contained a thousand times, we can see that the circumference of the Earth is a thousand times 55,000 yards, just as we should obtain the total circumference of the clock face by multiplying one of its divisions by twelve. But in order to know how many times an arc is contained in the circumference we must know the value of that arc in degrees, minutes, and seconds. Now, in order to know those degrees and minutes, we must consider the angle COA formed by the two lines which pass from the point on the horizon and from the summit of the tower to the centre of the Earth. We must study the angle COA which comprises between its sides the terrestrial arc BC, which we may regard as a huge protractor arranged for measuring that arc.

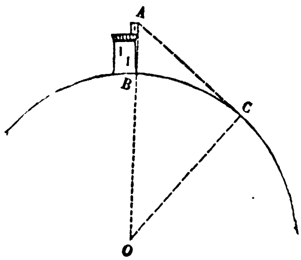


FIG. 18.

4. The question reduces itself to that of obtaining the value of the angle COA. But to obtain this angle what eye will go and place itself at the very centre of the Earth? It is an eye which sees the invisible, and measures the immeasurable. It is the eye of reason, the eye of Geometry. We may notice, in fact, that in the triangle ACO

the angle C is a right angle. That is certain, although we have not measured it, for it is formed by a radius OC and a tangent to the circumference; that is to say, the visual line AC which grazes the curvature of the ground at the horizon. If you do not see this, read the footnote below.[1] Since the triangle AOC is a rectangular one, the angle at A and the other angle at O, the centre of the Earth, together amount to 90 degrees. If we knew the first, the second would also be known, for simple subtraction would give it to us. Therefore let us measure the angle at the top of the tower.

We ascend to the top of our observatory and point one telescope of the theodolite towards the horizon, and the other towards the centre of the Earth. Here we seem to come across a difficulty. How can we point a telescope at the centre of the Earth, which is invisible and at an enormous depth under our feet? Yet it is quite simple. Suspend any heavy body, such as a ball of lead, by the end of a thread; take hold of the other end and let the ball go. When it has become motionless the stretched thread will indicate the direction of the centre of the Earth just as if the suspended body really saw that centre. In other words, the thread when produced

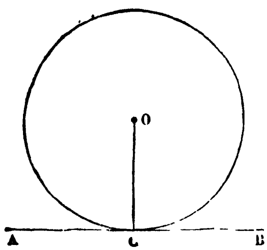


FIG. 19.

[1] The straight line which grazes a circumference and touches it at a single point without penetrating to its interior is called a "tangent," from a Latin word meaning "to touch." Such is the line AB (Fig. 19), which touches the circumference at the point C. If we draw the radius OC to the point of contact with the tangent, it is found in every case that this ray is perpendicular to the tangent, and makes an angle of 90 degrees with it. You may make the experiment on the diagram or on any figure traced by yourself.

through the ground would pass exactly through the centre of the terrestrial Globe.

5. The second telescope of the theodolite must then be directed along the plumb-line. Thus we obtain the value of the angle OAC. We find it to be 89 degrees 33 minutes. Therefore the angle at the centre of the Earth is 27 minutes, for these 27 minutes added to the 33 minutes above make 60 minutes, or 1 degree, and this degree added to the 89 degrees of the first angle gives 90 degrees, that is the amount which the two angles must total.

If the angle at the centre of the earth is 27 minutes, the terrestrial arc BC comprised within its sides is also 27 minutes. This is now the question: How many times is the arc of 27 minutes contained in the entire circumference, which amounts to 21,600 minutes? A division gives 800 for answer. The arc BC which we have found to be 55,000 yards long being contained 800 times in the total circuit of the earth, the latter must be 800 times 55,000 yards, or 24,900 miles. So the problem is solved, and the circumference of the Earth is known. A distance of a dozen leagues and an angle, that is all that science demands for achieving one of the most astonishing operations.[1]

Ah! if only Geometry had the attraction of "Cinderella" or other children's stories, what a lot we should have to ask of it! But for your young imaginations such things may not be, and I even have spoken too much about the triangle. Never mind. Considering the great question we have dealt with, you will forgive me if only I have made myself clear.

[1] It requires even less, for it is sufficient only to know the height of the tower and angle OAC to determine the circuit of the Earth. But then the calculation is too complicated for us.

6. If we cut an apple into slices with a knife, the sections are circles, which are larger or smaller as the knife cuts into a portion nearer the centre or farther away from it. If the knife passes exactly through the centre of the apple the circle of cutting is as large as it can be, and the fruit is divided into two equal portions. If it does not pass through the centre the circle cut is smaller and the apple is unequally divided. This shows that it is possible to trace on the surface of the sphere as many circles as we wish. The largest ones will divide the sphere into equal parts, while the smaller ones will divide it into unequal portions. The former are called great circles. They are all equal to each other, for however they are directed their radius will be the radius of the sphere itself, and they all will pass through the centre of the sphere. The others are called small circles, and their radius is smaller the farther they are away from the centre of the sphere.

The circumference of a sphere is always measured along a great circle. That is quite natural; for if you wish to measure the circumference of an orange you would not measure the smaller cut left by a knife in slicing off a portion of the rind, but you would measure the great section which plunges into the heart of the fruit and passes through its centre, that is to say, a great circle. The circuit of the earth means, therefore, any great circle ideally traced on the surface of the Globe. Thus the great circle of the Earth would be 24,000 miles round. The radius of this great circle, which is the radius of the Earth, would be a little less than 4,000 miles.

7. We may understand the imposing grandeur of these numbers by the following considerations. In order to

encompass a table, three or four or five of us join hands. In order to encompass the Earth in the same way, it would require a chain of people nearly equal to the entire population of France. A traveller capable of walking 25 miles a day, which is a great deal, would take three years to walk round the Globe if there were no oceans to cross. But what shanks could keep up such work for three years, considering that a single walk of 25 miles exhausts our powers and makes it impossible to start again next morning? Let us, then, consider those indefatigable travellers the clouds. They fly from one region of the Earth to another over all obstacles, over plains, mountains, and seas, with equal facility. That cloud which is just flying swiftly across the sky, what time would it take to travel round the Earth if the wind held in the same force and direction? It would take about six weeks, because a strong wind in a tempest hardly exceeds 25 miles an hour. It would take six weeks, and yet it goes so fast that its shadow runs along the ground with giant strides from hill to hill.

8. Let us try some other comparisons. Let us imagine the terrestrial Globe as a great ball 2 yards across, and then let us represent on it in the proper scale some of its principal mountains. The highest mountain of the Earth is Mount Everest, which forms part of the Himalayan chain in the centre of Asia. It raises its pinnacles to a height of 30,000 feet. It is only rarely that the clouds are high enough to crown its summit, and its base covers the extent of an empire. Now let us place this giant on the great globe representing the Earth. In order to represent it we should require a small grain of sand, one-twentieth of an inch high. The highest mountain in Europe, Mont Blanc, which is 16,000 feet

high, would be represented by a grain of sand one-half that size. It is unnecessary to multiply such examples. In comparison with us the mountains are immense, and they impress us with their enormous size, while in comparison with the Earth they are grains of sand lost in its colossal bulk.

And the seas, the deep and vast oceans, what are they relatively to the entire Globe? The seas cover nearly three-quarters of the surface of the Earth, and their average depth appears to be about 4 miles. In order to fill up their basins, should they run dry, it would require 1,000 rivers like the greatest river of France, the Rhône, flowing for 2,000 years to their fullest extent. Yet compared with the size of the Earth the enormous mass of the waters of the oceans is reduced to almost nothing. To represent it on our globe 2 yards across, a layer of liquid one-twentieth of an inch thick would suffice. A wet brush wiped over this great globe would leave behind enough moisture to represent the oceans.

The other ocean, the sea of the air, which is still more vast, since it envelops the whole of the Earth and rises to a height of some 40 miles, would be represented on the same globe by a gaseous layer as thick as a finger. Round a peach, the atmospheric sea would be represented with considerable exaggeration by the almost imperceptible down on the fruit.

9. You will now understand that, in spite of its chains of mountains and valleys, the Earth can justly be called round, for its curvature is less altered by these irregularities than is the curve of an orange with a fine skin by the slight wrinkles in its rind.

Let us add here some numbers relating to the dimensions of the Earth.

The Earth's circumference equals 24,900 miles.
The Earth's radius equals 3,963 miles.
The Earth's surface equals 198 million square miles.
The Earth's volume equals 262,000 million cubic miles.

The three last values are deduced by geometrical rules which cannot here be explained.

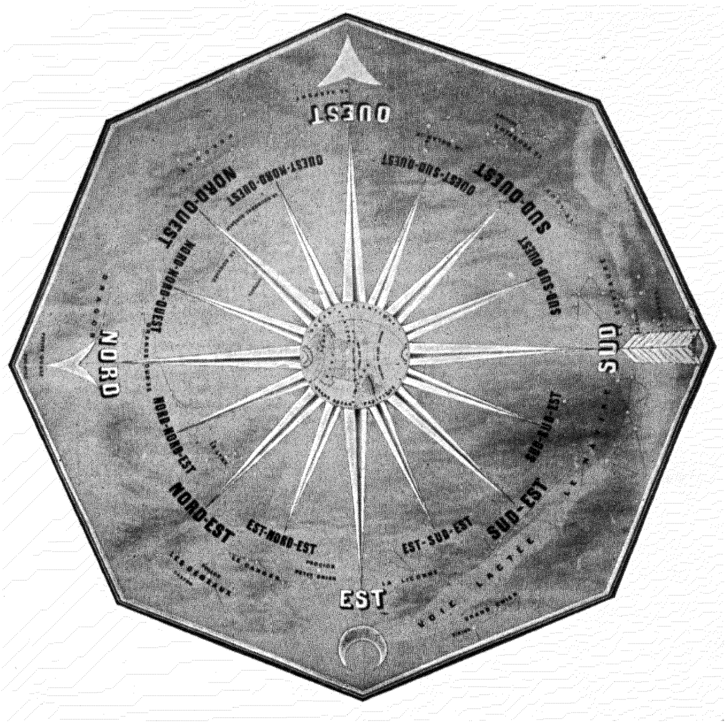
THIRD LESSON

HOW THE EARTH IS WEIGHED

The falling of bodies, 1.—Attraction, 1.—Deviation of the plumb-line near mountains, 1.—Cavendish's balance, 2.—A falling body directs itself towards the centre of the Earth, 3.—A two-horse vehicle, 3.—Attraction is proportional to the mass, 4.—It decreases proportionally to the square of the distance, 5.—Graphic representation of this law, 6.—A sphere attracts neighbouring bodies as if all its matter were assembled at the centre, 7.—Newton, 8.—The comparison of weights reduced to the comparison of falls, 8.—The Earth's weight, 9.—The lever of reason, 9.

1. ALL bodies raised into the air and left to themselves fall back to the Earth. In their fall they are directed perpendicularly to the terrestrial Globe, not deviating farther to one side than to another with respect to a level surface. They follow the vertical, that is to say, the plumb-line. If some shaft without end were open to their passage they would pass right to the centre of the Earth. Observation has shown that a freely falling body falls 16 feet in the first second of its fall. As it continues to fall it goes faster and faster, and the distance it passes through also increases rapidly. The number of feet fallen through is equal to 16 multiplied twice over by the number of seconds which elapses; in other words, it is proportional to the square of the time.[1] Thus, the space fallen through in 6 seconds is 60 multiplied by

[1] The square of a number is the product of the number multiplied by itself. Thus, the square of 5 is 25, the square of 7 is 49, and so on.



C. Divisions of the Compass in the Sky, seen from below.

[To face p. 22.

6 times 6, or 16 multiplied by the square of 6. The cause of the fall of bodies is the attraction of the Earth.

Matter attracts matter. This property, one of the most general of all properties, is called "gravitation." Two material particles, placed facing each other at any distance, mutually attract each other and tend to approach. If the bodies which we see before our eyes every day do not start moving towards each other by virtue of this mutual attraction, it is because they are, so to speak, fixed in place by their own weight, the result of the Earth's attraction, which is superior to any other attraction. It is also because they would have to surmount certain resistances with which their feebler attraction is not able to cope, such as the resistance on the part of the air and the resistance of the supports on which they rest. But if the attracting body is a great mass, and if the attracted body possesses sufficient liberty, then the attraction of matter to matter is shown by sensible effects. In a plain, the plumb-line hangs perpendicular to the ground along the vertical, but in the neighbourhood of great mountains it is somewhat deviated from that direction. Its ball is slightly deflected towards the mountain whose attraction rivals that of the Earth itself.

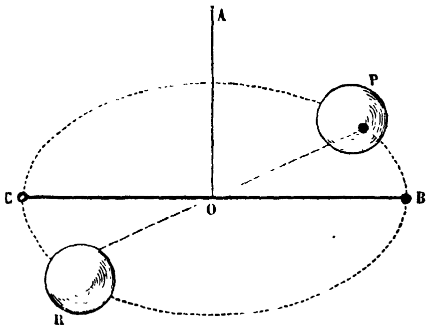


FIG. 20.

2. The attraction exerted by one body upon another may be also shown in the following manner. A thin wooden rod, BC (Fig. 20), a couple of yards long, is suspended

at its centre O by a fine wire fixed in a clamp at A. Two small weights are attached at the ends of the rod B and C, and their weights are exactly the same. These weights are in equilibrium, as are the weights in the two pans of a balance, and the rod with its weights is at rest in a horizontal position. Then a heavy ball of lead, P, is placed near the weight B, and another heavy ball of lead, R, of equal weight, is placed at the same distance from C on the other side. The result is that the rod holding the two similar weights twists the suspended wire and the two small weights try to move towards the lead balls which attract them.[1] The small weights fall towards these balls, but with a slowness of fall conditioned by the feebleness of the attraction urging them. Here the fall is not along the vertical to the attracting sphere, or along the straight line joining the weight to its centre. It takes place along the arc of a circle, that being the only direction compatible with the arrangement of the apparatus. But clever calculations enable us to deduce the fall along a straight line from the fall observed along the arc of a circle.

3. Since every body raised above the ground, and left to itself falls back, the Earth must attract it in the same way as the heavy balls of lead in our experiment attracted the small weights. Now this attraction is not exercised by one portion of the Earth more than by another; it is exercised by all the parts at the same time, by those above and below, on the right and on the left, on the surface and below it. From all these attrac-

[1] This apparatus is called Cavendish's balance, from the English physicist who first used it for weighing the Earth. Our elementary explanation forces us to simplify the apparatus considerably, with the sole object of explaining the principles on which the Earth is weighed.

tions, any one of which would attract the body towards itself, there results the total attraction which directs the fall of the body towards the centre of the Earth.

Take a two-horsed vehicle. If only the right-hand horse is harnessed, the carriage will tend to go to the right; if only the left-hand horse is put in, the carriage will tend towards the left; if both horses are harnessed, the carriage will go straight ahead. The same thing applies to a body at the time of its fall, for we can always imagine the Earth divided into two equal parts, one on the right and the other on the left of the body. If only the right half exerts its attraction, the body would tend to the right, and if it were only the left half it would fall to the left. But by the joint attractions of the two halves, or by the total attraction of the Earth, it falls towards the centre.

4. Let us go back to Fig. 20. By the attraction of the large ball of lead, P, the small weight B is drawn towards that ball. It falls towards it, but only slowly on account of the feebleness of the attraction. Let us imagine that the ball weighs 2 cwt., and that the weight falls through one twenty-fifth of an inch in the first second of its movement. What would happen if the ball consisted of a sort of lead made more compact by hard hammering? If, indeed, while conserving the same bulk it contained twice as much matter, and weighed 4 cwt. instead of two?[1] It is quite simple. Since every material particle of the attracting body acts on the attracted body, the more matter is contained in the attracting body, the more heavy and compact it is, the more powerful will be its attraction; and the ball con-

[1] This is pure supposition; no hammer, however powerful, could make lead twice as compact as before.

taining 4 cwt. of lead instead of 2 cwt. in the same volume would make the weight fall through twice the former distance. And if the ball were 3, 4, or more times as heavy, it would produce a fall, 3, 4, or more times as great. As it is, the Earth makes objects fall 16 feet during the first second; but if it contained two or three times as much matter as it does, it would make bodies fall through two or three times the space in the same time. Let us generalise this result and put it as follows: *Attraction increases in proportion to the quantity of matter in the attracting body.* Using the classical terms, we may put it thus: *Attraction is proportional to mass.* Mass here means quantity of matter.

5. The power of attraction diminishes in intensity if we place the attracted body farther away, and its initial fall becomes slower. We can already observe on the top of a high mountain that bodies fall less quickly than in a plain, which proves that at that distance from the soil the attraction of the Earth is lessened. According to what law does attractive force diminish? That is what we must now find out.

Let us go back once more to Fig. 20. The ball of lead, P, attracts the weight nearest it and makes it fall towards its surface by one-twenty-fifth of an inch during the first second, when the distance is, let us say, 3 inches from the centre of the ball to the centre of the weight. Now let us take the leaden ball to twice the distance, or 6 inches, and let us remove the ball R to the same distance. In these conditions the fall will also take place, but it will be 4 times smaller and will only amount to one-hundredth of an inch in the first second. At 3 times the distance the fall will be 9 times smaller than it was at first. Thus, at a distance 2 between the centres

the attraction is 4 times feebler than it is at the distance 1. At a distance 3 it is 9 times feebler. We may notice that 4 is the square of 2, and 9 is the square of 3. Hence the attraction diminishes in proportion to the square of the distance.

6. In order to become familiar with this fundamental law, we may represent graphically to some extent the force of attraction and render its diminution with the distance visible. But this must not be regarded as a demonstration, it is only a simple way of forming the image in the mind.

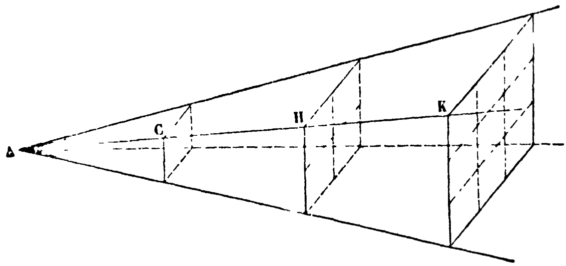


FIG. 21.

Every material point exercises its proper attraction all round. Let us represent the attraction emanating from that point in every possible direction by cords or hooks radiating out from it as the rays radiate from a luminous point. These hooks would seize everything they came across, and pull it towards the attracting point. The result produced would depend, of course, upon the number of hooks which seized the body in question, but not upon those which did not reach the body at all. Thus, let an attracting point A (Fig. 21) exert attraction upon a square, C, for example. From the point A, let us say, there proceeds in all directions a close array of

cords which can seize anything within range and drag it towards the point from which they come. The square of C will receive all these cords contained in the beam having the point A for its apex and the square C for its base. At a distance AH, double that of AC, it would require a square 4 times greater than the first, as seen in the figure, to receive all the cords contained in the same beam. Hence the first square C transported to double its distance would only receive one-fourth of the cords, and hence would undergo an attraction 4 times less. Similarly, in order to provide a grip for all the cords of the beam, when the distance is AK, or 3 times AC, it would require a square 9 times as great, and the original square C, transported to that distance, would only receive one-ninth of the total and would indicate an attraction 9 times less. The attraction of the point A on the square C, therefore, becomes 4 times, 9 times, or 16 times more feeble as the distance becomes double, treble, quadruple, etc.

7. We can, therefore, see that the distance must be reckoned from the material particle attracted to the centre of the attracting sphere, as explained in paragraph 5. Let us consider the attraction of the Earth. A weight is taken to the summit of Strasbourg Cathedral, which is 465 feet high. Left to itself, it falls by virtue of the undivided attraction exercised by every material point of the Earth. But not all these material points are at the same distance from the weight by any means. Those on the surface, at the foot of the tower, are only 465 feet away, while those in the interior of the Earth are farther away in proportion as they are farther below the surface. Those at the centre of the Earth are at a distance of 465 feet plus the length of the radius of the

Earth, while those on the other side of the Globe are farther away by another radius. Besides these, there are masses to the right and to the left in infinite variety, near the surface or far below it, in front and behind, and nearer or farther away from the falling body. Each one of these material particles acts more or less energetically upon the attracted body according to its distance. How can we find the result of all these elementary attractions, which vary from one point to another? We find it by supposing that all the material points of the Earth are at the same distance from the attracted body, a distance intermediate between the smallest distance, 465 feet, and the greatest distance, the diameter of the Earth plus 465 feet. We suppose, indeed, that all the attracting points are at the distance of the centre of the Earth. This implies that the points on the upper half of the Earth lose attractive power because they are supposed to be farther away. But the points of the lower half gain in the same proportion because they are brought nearer. The two opposite results compensate each other on account of the perfect symmetry of the two halves of a sphere. Hence we obtain this third law: the material points uniformly distributed in a sphere together act on an external point as if they were all placed at the centre of a sphere. Hence, when it is a matter of the attraction exercised by the spherical body we need not worry about the more or less great distance between the attracting points and the point attracted, since all the points can be supposed to be united at the centre of the Earth. There is only one distance to consider, the distance between the Earth's centre and the point attracted.

8. The laws of attraction were discovered by Isaac Newton, one of the greatest of human geniuses. Newton

arrived at them not by the rather elementary and somewhat loose reasoning I have had to employ in order to make myself clear, but by considerations of the highest order based upon astronomical facts. We shall later have occasion to follow the thought of Newton more closely.

Of what use are these laws? you will ask, no doubt, and what is Newton's merit in having discovered them? These laws, children, are among the most beautiful things we know, for they explain to us the mechanism of the world and reduce the divine harmony of the universe to a sublime problem of mathematics. To give you an idea what these laws teach we shall use them for weighing the Earth. Yes, for weighing the Earth, the enormous globe which staggers our imagination when we seek to picture its size. We shall put it in the balance of the Newtonian laws and determine its mass just as if it had been possible to put it into a real balance against pounds in the other pan.

The attraction is proportional to the mass of the attracting body, to its weight, to the quantity of matter. Thus, when a ball of a certain size placed in front of the weight B of Fig. 20 attracts that weight and makes it approach a little in a second, another ball of double, treble, or quadruple weight placed at the same distance would make it approach twice, three times, or four times as far. If the weight of the first ball were known we should know the weight of the second as soon as we had ascertained how many times more the attracted body had approached it. The comparison of the weights of the two balls is thus reduced to the comparison of the distances traversed in a second by a small weight under the influence of their attraction at the same distance.

The ball which will make the small weight cover twice or ten times the distance will be twice or ten times heavier respectively.

9. A similar reasoning applies to the Earth. In order to know how many times the terrestrial Globe surpasses the weight of a certain globe of lead it is sufficient to know how many times the fall of a weight in one second under the influence of the Earth exceeds its fall under the influence of the mass of lead provided the distances between the attracting bodies are the same in each case. Now let us repeat the experiment of Fig. 20. Let us put in front of the weights B and C and a yard away from their centres two heavy balls of lead. The weights will be displaced, and will move towards the neighbouring balls, traversing, let us suppose, a twenty-fifth of an inch during the first second of this sort of fall. Knowing that a weight falls by that amount per second towards the big ball of lead when it is a yard away we can calculate how much it would fall if the attracting body, instead of being a yard away, were as far away as the centre of the Earth, i.e. 4,000 miles away. The diminution of attraction in proportion to the square of the distance teaches us that the weight would fall one-twentieth of an inch divided by the square of the distance in yards, which amounts to a little over 40 million million. I leave you to make the division if you like. Without performing that arduous operation it is obvious that the quotient will be excessively small. It represents the quantity by which a small weight placed here would descend in one second towards the ball of lead if the latter were at the same distance as the centre of the Earth. But the Earth, of which we need only consider a single point, the centre—where the whole material of the Earth may

be considered to be collected—the Earth, I say, under the same conditions of distance and time would make the weight fall 16 feet. Let us then find out how many times the excessively small figure found above is contained in 16 feet, and we shall know how many times the weight of the Earth exceeds the weight of the ball of lead. It is thus found that the weight of the Earth in pounds is expressed by the figure 13 followed by 21 ciphers. We should call it 13,000 trillions of pounds. From this enormous weight and volume of the Earth we may deduce that if all the materials of our Globe—air, water, stone, metals and minerals—were perfectly mingled, each gallon of the mixture would weigh 55 lb.

Our task is done. The Earth is weighed. What lever, what power have we used? We have used the power of thought which God has planted in us so that we might decipher to His glory the riddle of the Universe, the lever of reason which is capable of raising the heavy burden of the Earth.

FOURTH LESSON

THE EARTH TURNS

What is a fall? 1.—Why the Earth does not fall, 1.—Apparent rotation of the sky, 2.—Illusion produced by a train in motion, 2.—Upside down for 12 hours, 3.—Why we do not fall, 3.—The speed of the Earth and the speed of a bullet, 4.—The wing beat of a gnat, 4.—Strange consequences of the earth's stoppage, 4.—The eternal economy, 4.—The pendulum, 5.—Invariability of its plane of oscillation, 5.—The cart-wheel, 6.—The Earth's rotation shown by the pendulum, 6.—The Earth's rotation shown by trade winds, 7.—The spectacle of the revolving Earth.

1. THE Earth, isolated all round, swims in space without any support. Then why does it not fall, seeing that it is so heavy? Let us first solve this difficulty. What do you see above your heads? An expanse, a space, the sky. What would you see on the other side of the Earth, on the opposite side of the Globe, on the point corresponding to our feet? The sky, always the sky. Unlimited space, or the sky, as we call it, extends, indeed, in every direction round the Earth. Then what direction in this space could the Earth take for falling? Which direction is down, and which up? If upwards is towards our sky, remember that the sky is also on the opposite side of the Earth, and that it is quite similar to our sky here, and is the same everywhere. If it seems obvious to you that the Earth will not rush into the sky above us, why should it rush into the sky below us? To fall into the opposite sky would be to rise as a balloon

rises here on leaving the ground. You have never asked yourselves why the Earth does not ascend into the sky. Then do not ask yourselves why it does not fall, because the two questions mean the same thing. To fall means to approach a body which produces that fall by its attraction. If there were nothing beyond the Earth, there would be no attraction exercised on our Globe, and its fall in any direction whatever would be impossible. Thus the Earth would remain for ever motionless in that position in space where the Creator placed it. Or, on the other hand, once thrown by the Divine Sower, it would travel across space in a straight line without end. But if there is in the sky a heavenly body whose attractive force could master the Earth, then I admit it must fall towards that dominating body. In reality, the Earth does fall, but not as we imagine it. It falls towards the Sun, whose powerful mass attracts and drags it incessantly. We shall, later on, return to this important question.

2. The heavenly vault appears to us as a hollow sphere of which we occupy the centre, like a round dome in which the stars are fixed. In twenty-four hours of uniform motion, that heavenly sphere seems to turn all in one piece round the Earth and carry with it its legion of stars. But the telescope shows us that the heavenly vault is an illusion of perspective. It teaches us that open space extends in every direction around us, without any limitation of our view. It teaches us that the Sun is not a small luminous disk, but a material body immensely greater than the Earth, and that the stars, which seem to be only sparks, are comparable in brilliance and in volume to that celestial giant. Lastly, it proves that the stars, instead of being at the same distance

from us, are at various distances, some greater, some smaller, but always immeasurably greater in the depths of space than is suggested by their simple appearance. Then a doubt arises in our mind, whether that immensity, with its innumerable population of colossal stars, actually turns solidly round the Earth from east to west; is it not, rather, the Earth which turns itself in the opposite direction? The stars would still appear to rise in the east and set in the west, while we, unconscious of our own rotation, should regard ourselves as being at rest. In a railway carriage, everyone has noticed that the trees bordering the line, the posts, hedges, houses, seem to run rapidly in the direction opposite to our own. We consider ourselves at rest, and imagine that the external objects are in rapid motion. Were it not for the shocks of the carriage, the illusion would be complete. We could imagine the country to be madly flying and twisting. A simple horse carriage or a boat, carried along by the current of the river, would lend themselves to this same curious observation. Thus, every time a gentle movement takes us in one direction we lose consciousness of that movement, and the neighbouring objects, which are really at rest, seem to move in an opposite direction.

3. If the Earth turns on itself from west to east, we are not conscious of that movement because there is no shock or oscillation of any kind. Thus, we firmly believe we are at rest while the different celestial bodies seem to be moving and turning in the direction opposite to our own displacement, that is to say, from east to west. The rotation of the sky and its stars round the Earth might then well be an illusion absolutely parallel to that which is produced by the trees of the country running

in the opposite direction to the train which takes us along the railway. Is it really the sky which turns, or is it the Earth ? If it is the Earth, the following difficulty will occur to you. The terrestrial Globe rolls in space and makes a complete turn on its axis in twenty-four hours. In half that time we must make half a revolution with the Globe which is carrying us, and we must find ourselves in a position the opposite of that in which we were at first. At the present moment we have our heads up and our feet down ; twelve hours afterwards it will be the contrary, we shall have our heads down and our feet up. We are upright now, in twelve hours we shall be upside down. Why does that uncomfortable position not inconvenience us ? Why do we not fall ? It might seem that we should have to grip the soil desperately in order not to fall into the abyss. The observation is justified to a certain extent. It is true that in twelve hours from now we shall be in a position inverse to our present position ; our head will be pointing where our feet are pointing now, but in spite of this reversal there will be no danger of falling nor the least inconvenience of any kind, for our feet will still be downwards resting on the soil, and our head will be in the air pointing to the sky, because the sky surrounds the Globe on all sides. You must understand, once for all, that in space, which is similar in every direction, the words up and down are meaningless. These words only mean something with respect to the Earth. " Down " means towards the soil, " up " means towards the enveloping space. But as we are always held together by the attraction of the Earth, in spite of its revolutions, with our feet on the ground and our head towards the sky, we always find ourselves in an upright position

without any danger of falling into a space where nothing attracts us, and no giddiness or any other inconvenience lets us suspect our reversal every twelve hours.

4. So much, then, is clear; in turning, the Earth does not threaten to throw us off. But there is another difficulty, a greater difficulty. How can we believe that the Earth, whose weight staggers the imagination, turns obediently round an imaginary axis? What force does it require to keep such an enormous round machine in motion, and at such a speed? If the Earth accomplishes its revolution in twenty-four hours, the points on its middle region which travel along a great circle will in the same time travel 25,000 miles, or 1,500 feet per second. That is approximately the speed of a shot leaving the cannon's mouth. Mountains, plains, and oceans revolve in a perpetual circle with a formidable speed of a quarter of a mile per second. How can we realise such movements of such masses? I agree that to set the mass of the Earth in motion, all our mechanical means joined in a common effort would be of no more effect than the wing beat of a gnat trying to move a mountain. To communicate to that mass the speed which animates it now, and to carry along continents with the speed of a cannon shot would require a power which the mind cannot conceive. But suppose the Earth at rest and you will see what strange consequences will befall. If the Earth is at rest it must be the stars which turn exactly in twenty-four hours. The Sun, as we shall see in the coming lesson, is a globe of matter 1,400,000 times greater than the Earth. You want to leave the Earth at rest because it is too heavy? Well, then, the Sun must turn (the Sun in comparison with which the Earth is a miserable little fragment of clay),

and it must hurry because the way is long! Consider its distance—it must cover 5,730 miles per second in order to accomplish its revolution in twenty-four hours. But that is not all. The stars are comparable in size to the Sun itself. The nearest to us, if it revolved round the Earth, would have to cover 620 million miles per second. Others, 100 or 1,000 times farther away, would have to cover distances 100 or 1,000 times greater. If the Earth does not turn, it follows that these innumerable bodies, immensely heavier and larger than our Globe, would turn not with the speed of half a mile per second, but of several thousand miles or several million miles. Such mechanism is contrary to reason, it is opposed to the eternal economy which never spends a thousand where one suffices. It must be the Earth which turns, having been set in motion once for all on its axis.

5. In spite of its great rapidity, the movement of rotation of the Earth is so gentle that we can in general not perceive it, or even suspect it. We are carried along with the objects about us, we find them always in the same position with respect to ourselves, and from this permanence of relative position we draw the conclusion of immobility. Yet there are certain ingenious means by which we can convince ourselves that the ground moves under our feet, and we can experimentally show the rotation of the Earth. Let us take the simplest example.

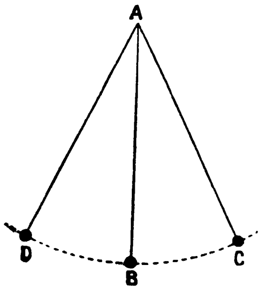


FIG. 22.

At the end of a wire a ball of lead is suspended. If the upper end of that wire is fixed at A (Fig. 22) the ball will remain motionless

after a few oscillations, and the wire will, of course, take the vertical direction. Let AB be this direction. Now let us put the ball into the position C and let it go. If the wire did not hold it back it would fall in a vertical line, but it cannot do so on account of the wire, and thus, drawn by the attraction of the Earth in the only direction compatible with the bond which attaches it to its point of suspension, it moves along the arc of the circle DC, whose centre is at the point of suspension. It thus attains the position B, and will then pass it to climb along the arc to D. Having arrived there, it falls back, or rather it slides back along the arc to C, after which it goes back again to D, and so on for a long time until gradually the resistance of the air stops its movement, after a considerable time, which is longer if the point A is carefully fixed. Each complete going and coming of the ball from C to D and back from D to C is called an "oscillation," and the apparatus itself, the ball and its wire, is called a "pendulum." The oscillations of the pendulum are occasioned by the same force which produces the fall of bodies left to themselves, that is to say, the attraction of the Earth. They constitute a sort of fall modified by the suspended wire. The ball, in its to-and-fro movement, glides along the arc of an imaginary circle alternately from right to left and from left to right, without ever changing its route. It may travel through a smaller extent of the arc as its movements subside, but it never abandons its first route for another. It would be useless to prolong the oscillations, if we could, even for years; for unless an external cause modified its route, the ball would always keep in the same arc going to and fro. To sum up: the arc of oscillation of a pendulum is invariable in its direction,

for the instrument contains no element which could deflect the ball from the original arc either in one sense or another.

6. Take a cart-wheel placed flat on the ground (Fig. 23), and above it facing the hub let us make a pendulum oscillate. The arc BC will have a certain direction corre-

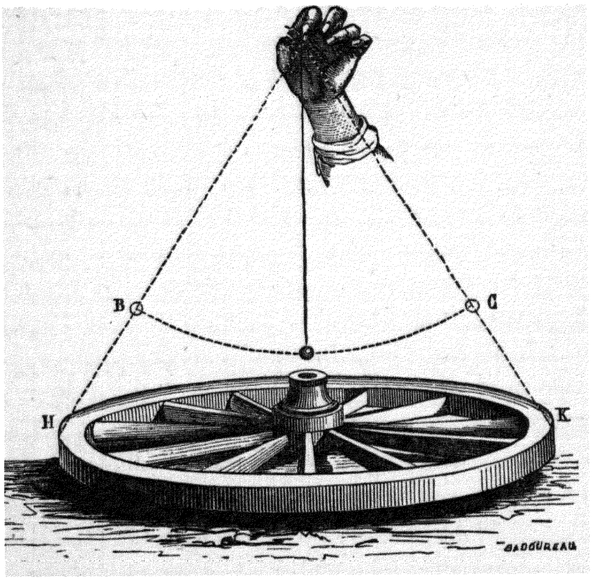


FIG. 23.

sponding to, say, the points H and K of the wheel, and we can mark those points. If the wheel is at rest, the arc BC being invariable, the pendulum will always have its extreme points at the points H and K marked, which may be on the wheel. That is obvious; but if the wheel turns on its axis, the points H and K will be displaced and their places will be taken by other points, which in

turn will be marked out by the pendulum. That also is quite simple. But if the movement of the wheel is hidden from us in some way, and if we do not know of that movement, what will happen ? It is, after all, an illusion corresponding to that produced by the trees of the country seen from the railway train. We believe that the arc of oscillation, in reality invariable, is gradually turning and being displaced, because the pendulum will be pointing towards different points of what we believe to be an immovable wheel. If the wheel is turning from right to left, the arc of oscillation will seem to us to be turning from left to right.

Now imagine a very long pendulum suspended from the ceiling of a hall, and having a large cannon-ball instead of a bullet. The pendulum is in movement, it comes and goes with majestic slowness. At one moment the cannon-ball points at a particular part of the hall, a little afterwards it marks a more westerly point, and still later, a third point still farther towards the west, so that the arc of oscillation is gradually displaced from east to west. Is it really that the arc changes its direction ? No, you know that it cannot vary. Therefore it must be the floor of the hall which is displaced, the ground itself which moves, it must be the Earth which turns from west to east.

7. A very remarkable proof of the rotation of the Earth is furnished by the trade winds. These are the winds which all the year round go from east to west in the equatorial regions. The first navigators who adventured across the Atlantic with Columbus saw the cloudy strips which a permanent breeze stretches along the equator, and seized with terror before the inexorable constancy of the easterly winds which urged them towards the

unknown, they asked themselves if they could ever get back to their country. The Earth's rotation accounts clearly for the singular permanence of these trade winds. The equatorial regions are the hottest on earth. Starting from there, the temperature greatly diminishes in both hemispheres down to the poles of the Earth. The hot air, which is also lighter, rises up from the equatorial countries into the higher regions of the atmosphere, and is replaced by the cold and heavier air flowing in from the north and the south. If the Earth were immovable, there would then be, in these equatorial countries, a continual wind flowing from north to south in the northern hemisphere, and from south to north in the southern hemisphere. But because of the rotation of the Earth from west to east, the direction of these continual winds is changed. As a matter of fact, the mass of the cold air on approaching the equator has a certain speed of rotation common to the atmosphere and to the Earth. That speed is not the same everywhere, because the circle described round the axis is not of the same size in every part of the Globe, being greatest at the equator where the circle is greatest and diminishing gradually towards the poles where it is zero. Thus, the air of the cold regions having a speed of rotation from its starting-point, advances towards the equator with a speed insufficient to follow the general movement. It is slow with respect to the Earth; and, as the latter moving from west to east, encounters that slow mass of air, the same effect is produced as if the air were really displaced from east to west on a motionless Earth. The continual blowing of the trade winds is therefore a great disturbance created by the turning of the Earth in the mass of air continually moving from both hemispheres to answer

the call of the heat, but too slow a fall to follow the rotation of the equatorial regions.

8. Every twenty-four hours the Earth makes one complete turn. To this spot in space in which we are now other people will come, carried along by the Earth's rotation; oceans, far-distant regions and snow-clad mountains will take our place, and to-morrow at the same hour we shall be back here. In the place where you are reading these lines the sombre waves of the Atlantic will roll soon and will replace the sound of your voices by the great voice of their flood. In less than an hour the ocean will be here. Some great warship, with all its guns, will perhaps float in this very spot. The sea passes. Now it is the turn of North America, the Great Lakes of Canada, and the interminable prairies where the redskins hunt the buffalo. Then comes another sea, larger than the Atlantic. It takes some seven hours to pass by. What is this chain of islands where fishermen clad in furs are drying herrings? It is the Kourile Islands, to the south of Kamchatka. They pass quickly so that we can hardly catch a glimpse of them. Now it is the turn of the yellow faces, the Mongols and the Chinese, with their slanting eyes. What curious things we might see here, but the Globe rolls on, and China is already far away. The sandy uplands of Central Asia and mountains higher than the clouds follow on. Here are the pastures of the Tartars with their herds of horses. Here are the Steppes of the Caspian with their flat-nosed Cossacks, then South Russia, Germany, Switzerland, and, lastly, France. The Earth has made one turn.

You must not think that this giddy spectacle of the Earth passing by with the speed of a cannon-ball is visible in any way but in your mind's eye. If we rise

into the air in a balloon you might think that we ought to see the Globe rolling under our feet with its land and water. Nothing of the kind, for the atmosphere turning with the Earth carries the balloon with it in the general rotation instead of leaving it in one place as it would have to do in order to enable the observer to see the various regions of the Earth in succession.

FIFTH LESSON

CENTRIFUGAL FORCE AND INERTIA

The axis and the poles, 1.—The equator and the parallels, 1.—A glass of water inverted without spilling, 2.—A thread broken by rotation, 2.—Centrifugal force, 2.—The globe of oil, 3.—Deformation of a turning liquid sphere, 3.—Polar flattening and equatorial bulging, 4.—Fluid state of the Globe, 4.—Antagonism between centrifugal force and the Earth's attraction, 5.—A world without gravitation, 6.—A dying, immovable Earth, 7.—The pebble by the wayside, 8.—Inertia, 9.—A wheel set in motion, 10.—The Earth preserves the sum of its mechanical energies, 10.—Its invariable rotation, 10.

1. If we wished to represent the rotation of the Earth by means of an orange we could stick a knitting-needle through it and make it turn about that as an axis. The poles would then be the two points where the needle pierces the rind. In order to help our imagination we might suppose that the terrestrial Globe is pierced like the orange by a long needle round which it rotates every day. Such an imaginary needle would, like the real needle of the orange, be called an axis, and the points where it pierces the surface of the Globe would still be called the poles. Hence we call the axis of the Earth that ideal line about which the Earth performs its daily rotation, and the poles are the two points where the axis pierces the surface of the Globe.

Let us return to our orange and make it revolve round the needle. Every point in its surface turns in a circle

perpendicular to the needle, which is large or small according to the distance between the point and the nearest pole. At the poles themselves the circle described is nothing. At a distance from it it becomes larger as the point approaches the middle region of the orange, and at last in this middle region at equal distances from the two poles the circle is largest of all. All this applies word for word to the Earth. The various points of its surface revolve round the axis in unequal circles. The points at equal distances from the two poles move along the greatest circle of all, which is called the equator. The others describe circles called parallels, which are the smaller the nearer those points are to the pole. For the sake of expression these different circles, the equator and the parallels, described about the axis by moving points on the Earth's surface, are supposed to be traced on the Globe, and then the equator can be defined as a great circle at the same distance from each pole, and the parallels can be defined as smaller circles parallel to the equator. The equator is obviously unique. It divides the Earth into two equal parts or hemispheres, the northern hemisphere on the side which we inhabit, and the southern hemisphere on the opposite side. The parallels, on the other hand, are indefinite in number, and we may conceive as many on the surface of the Globe as we wish. Each of them divides the Earth into two unequal portions. All the circles, both the equator and the parallels, are perpendicular to the axis, and have their centres on that axis. None of them has anything but an imaginary existence, and we must not materialise them by conceiving the Earth as encircled like a barrel.

2. Up to the present we have considered the Earth as spherical, but for slight irregularities on its surface.

That is not altogether correct. The Earth, as we know from exact observations, is slightly bulged at the equator and flattened at the poles. The difference between the radius at the equator and the radius at one of the poles is 13 miles, the equatorial radius being the longer. Such a difference would, on a sphere 6 feet across, amount at the most to an eighth of an inch, and could therefore not be detected by the eye. The equatorial bulging and the polar depression do not therefore sensibly alter the round shape of the Earth.

The slight deformation of the poles and of the equator is occasioned by the rotatory movement itself. Some experiments will clearly prove this. To the end of a string tie a glass half-full of water and swing it round in a circle like a sling. During its rotation the glass is sometimes inverted, and at other times more or less inclined. Yet if it turns quick enough it will not lose a drop of water in spite of its inverted or inclined position. On the contrary, the water is pressed down on the bottom of the glass as if by force. If the glass were to remain at rest at the top of the circle the water would obviously at once be spilt. It is therefore the movement of rotation which keeps the water in the inverted glass and presses it towards the bottom.

Tie a stone to a thread and swing it quickly round. Do you not feel the thread stretching more and more as the stone gets quicker? Accelerate it further, but see that nobody is within reach. Make it go faster and faster. Snap! The thread has been broken and the stone flies off. While turning, the stone made an effort to get away from the hand, the centre of its rotation, and that gave rise to the stretching of the thread. When the effort became sufficiently powerful the thread, stretched

beyond its strength, finally broke. Thus, every body in a rotatory movement is, by the very fact of that movement, subjected to a special force which tends to remove it from the point about which it is turning. This force, due to the rotation, is called " centrifugal force." It is the more powerful the greater the velocity of the body. It is centrifugal force which urges the water to press against the bottom of the revolving glass and prevents it from spilling in spite of the slanting or complete inversion of the glass. It is centrifugal force which stretches the thread of the sling and breaks it at a certain speed.

3. Centrifugal force distorts a sphere which turns about its axis; it flattens it at the poles and makes it bulge at the equator, provided, of course, that the sphere is soft enough to obey the pull of the rotatory movement. In order to verify this fact one must first obtain, in a manner now to be described, a sphere endowed with the required flexibility. When poured into water oil will float, whereas in alcohol it will go to the bottom. It is lighter than water and heavier than alcohol. But in a suitable mixture of water and alcohol the oil will float in the middle of the liquid and will form a beautiful sphere as large as an apple (Fig. 24). Softly suspended in the liquid which supports it on all sides the ball of oil makes a wonderful object which immediately reminds us of the Earth, a giant ball suspended in the void. Let us suppose the globe of oil pierced through the middle by a long needle made to turn rapidly and smoothly by clockwork. On account of its friction the needle will gradually drag along the oily sphere and will impart to it its own rotatory movement as if both were part of the same body. As soon as the globe of oil turns it is seen to flatten at the points where the needle pierces it,

that is to say, at the poles, and it bulges in its middle region, that is to say, at its equator (Fig. 25). The polar flattening and the equatorial bulging become more pronounced as the rotation is accelerated. Nothing of the kind would happen if the sphere consisted of solid and resisting matter, because then that matter would not have the necessary mobility to obey the centrifugal force.

4. There is not much difficulty in understanding the deformation of a liquid sphere turning round an axis.

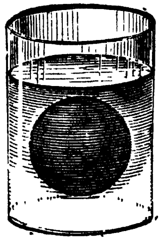


FIG. 24.

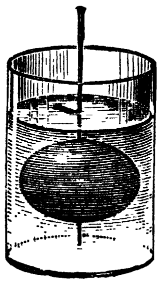


FIG. 25.

The points on its equator have the greatest velocity because they describe the largest circle. The points situated near the poles are almost motionless. For the former the centrifugal force has its greatest value, while at the poles themselves it is zero. Thus the material points of the equator must, in obedience to the centrifugal force which urges them onwards, get away from the axis as far as the cohesion of the particles permits, and the void produced in the total mass by that departure of the equatorial particles is filled by neighbouring matter, and this produces gradually a flattening at those points where no centrifugal force is felt, that is to say at the two poles.

It is true that the terrestrial Globe is not, like the globe of oil, entirely composed of a fluid substance. But the waters of the oceans fill nearly three-quarters of its surface, and to this liquid mass we must apply what we have learnt concerning the effects of centrifugal force. Thus, on account of the rotation of the Earth on its axis, the oceans have lost the exactly spherical form. They have been depressed at the poles and elevated at the equator in a sort of pad 13 miles high, which is held up by centrifugal force. And further, since geometrical measurements show the same deformation in the continents, the Earth must originally have been entirely liquid, and must while hardening through the ages have preserved for ever the configuration imparted to it by centrifugal force. An attentive study of the Earth shows, in fact, that the hard rocks forming the foundations of the continents were fluid in ancient times, as liquid as the molten metal in a furnace. It proves that before rising into the realm of the clouds the material of which mountains are composed formed part of a universal ocean of fused minerals.

5. Centrifugal force tends to remove bodies from the surface of the Earth, while the Earth's attraction tends to keep them in their place. There is therefore antagonism between these two opposite tendencies, but since attraction is the stronger of the two the bodies will remain on the surface of the Globe, or will fall back if removed from it. Yet we may conceive that centrifugal force might become equal to attraction, or even superior to it if the rotation were sufficiently rapid, for we know that the amount of the force increases with the speed of rotation. Calculation shows that if the Earth revolved round its axis 17 times faster, and accomplished one turn

in 85 minutes instead of 24 hours, the centrifugal force would equal the attraction at the equator, where the movement is fastest, and bodies would not fall in that region of the earth. A stone raised above the ground and left to itself would remain in the air without any support, being equally attracted towards the centre by the action of the Earth and repelled from the centre by centrifugal force. Liquids would no longer flow. A vessel filled with water and turned upside down would not lose a drop of its contents, just as we have seen in the case of the glass swung round in the manner of a sling. Bodies would lose their weight. It would be as easy to raise a piece of a mountain with the hand as a simple pebble. There would be no falling. If we were thrown from a height we should, instead of reaching the ground, remain suspended in the air by the Earth's rotation.

6. It would, indeed, be a singular world where the centrifugal force would annul attraction. You imagine it would be a pleasant world. You think how easy it would be to pile mountain upon mountain like the Titans in the fable. You think of the mad jostling we could indulge in without danger. But you must also remember that the sea drawn to the equator by an exaggerated centrifugal force would collect there altogether and would dominate the continents with its threatening bulk; that the rivers, no longer following the slant of the ground, would cease to flow; that clouds would no longer pour upon us their beneficent rain, since water would no longer fall; that our buildings, whose solidity is due to the pressure of their heavy materials, would have no resistance as soon as those materials lost their weight and would fly away at a breath like tufts of wool; and that we, ourselves, would roam here and there at the

pleasure of the wind unable to find a footing. Believe me, weight is an excellent thing. Sometimes, indeed, it makes us disagreeably heavy and breaks our bones in a fall, but on the other hand it gives a much-needed stability to our existence.

Let us suppose that the Earth rotates even more rapidly and makes a turn in an hour or less. Then the centrifugal force will be superior to the weight, and everything will be upset. The atmosphere forsakes us. It will be torn away in wisps and be lost in space. The sea also abandons us. Its waters, no longer restrained by gravitation, will roll from continent to continent over the highest peaks and will ascend into the air in wild eddies. The soil, the stones, the animals, the plants, all that is not fixed to the surface of the Earth will rush away never to return, as if thrown by some giant's sling. Nothing will remain of the original Earth but a skeleton of bare rock from which centrifugal force can detach nothing more. You have seen a cart-wheel rolling over a muddy lane and throwing off lumps of mud when it is moving fast. That is what the Earth would do if the revolution round its axis occupied less than an hour. It would project into space and lose for ever everything that has no solid roots in its rocky frame.

7. The consequences of a gradual stoppage of the rotation of the Globe, and still more of a sudden stoppage, would be very formidable. In the first place the oceanic bulge, no longer supported by centrifugal force, would subside and, flowing back to the two poles, would flood what is now dry land. Both night and day would be lengthened, the rotation would become more and more sluggish, and the present climates would be radically changed, to the dire peril of organised beings. When

finally the Earth ceased to turn, the hemisphere last facing the Sun would have perpetual day, an implacable day incompatible with the welfare of living beings, which require every now and then the rest and freshness of the night. The opposite hemisphere would be plunged into darkness and perpetual winter. From the moment that the Earth stopped on its axis it would be dead. Shall we be projected from this Earth by an excessive speed of rotation and flung sooner or later into the abysses of space ? Or will the Earth's speed slow down and the Earth stop on its tired axis like a wheel which, once started, expends its movement and falls back into rest ? Is it possible for the Earth to be accelerated or retarded in its rotation ? No, nothing of the kind is to be feared, as we may see from what follows.

8. A pebble lies by the roadside. How long has it been there lying on the dusty ground ? Nobody can tell. If it is not kicked by the feet of the passers-by, if nothing comes to draw it from its state of rest, it will always be found where we see it to-day, for it is quite unable by itself to escape from its immobility. Matter is inert and cannot set itself in motion on its own account. Every day experience shows this. But let us take this pebble in our hand. Thrown by our arm it rolls along the road. It knocks and rebounds against the inequalities of the soil, it sticks in the ruts or traverses them at the expense of its speed. Its impulse is absorbed in sand or mud, and it is finally stopped. If the road had been smoother the pebble would have travelled farther, for the fewer obstacles it encounters and the less friction there is on rugged surfaces the less of its velocity will be lost, and it will be able to cover a greater distance.

A round stone thrown along the surface of a frozen

pond travels so far that it looks as though it would never stop. On ice as smooth as a mirror the projectile has no such resistance to overcome as it has on the road, so it preserves its impulse better. Thrown as before it covers a much longer distance. Yet it comes to rest, and for a good reason. Even in this case there are obstacles on the polished surface which gradually consume the first impulse. These are the friction of the stone against the ice and the resistance of the air. Since a body once projected covers the greater distance the less the number of obstacles it encounters, it seems probable that the cause of the stoppage which occurs sooner or later resides entirely in resistances outside the moving body.

9. Further reflection changes our supposition into a certainty. It shows that if there were no resistance at all, the body projected would never stop. Why should it stop, indeed, since nothing is opposing the impulse which animates it? In order to stop, it would have to annul the impulse itself. It would have to destroy it by an opposite impulse derived from its own energy. It would mean that matter has the faculty of creating an impulse in its mass and setting itself in motion of its own accord. Since matter is unable to quit a state of repose, it is also unable to quit a state of movement. To return to immobility would imply the annulling of the first impulse by an equal and opposite one. To say that matter cannot set itself in motion implies that it cannot stop its motion. In the absence of any obstacle, a body after receiving an impulse is therefore endowed with a perpetual motion. And it must always move with the same speed, for to accelerate or slow down that speed would amount to the body itself producing an impulse forward or backward. It must move in a straight line,

since no reason exists why it should deviate from that line in one direction or another. To sum up: Matter having no will of its own, and being as indifferent to a state of rest as it is to a state of motion, presents the fundamental property which is called inertia, and which represents that indifference. A body at rest persists in that state until a force from outside disturbs it, and the body, once freely projected, moves perpetually at the same speed along a straight line without end.

10. A wheel is suspended in the air and carefully balanced on its axis. We set it moving with our hands. One, two, three, it is started, it is turning. How many turns will it make if left to itself? Sometimes many, sometimes few, for here also the impulse is gradually annulled by the resistance to be surmounted, friction on the axis, or the resistance of the air. According to the amount of this resistance, rotation will last a longer or shorter time. If the shaft is greased and smooth, the wheel will make a great number of turns. If it is rough, if it creaks, or if it is rusty, it will only make a few. But it would be useless to put the best lubricator on the shaft, since the friction of the shaft is never zero, and the wheel will always stop in the end if only on account of the resistance of the air. Yet our reason tells us that because of the inertia of matter, if all resistance could be suppressed, the first impulse would remain intact, and the wheel would turn without end at a steady speed. Let us repeat it, for it is very important: In itself, an inert body has nothing which could modify an impulse imparted to it. Unless outside resistance comes to destroy its motion, it will always, when left to itself, move in a straight line for ever. If it is made to rotate, it will rotate for ever.

Mechanically the Earth can be compared to that wheel, but in this case there is no resistance intervening to stop the rotation. The axis is not a shaft of iron, it is an ideal pivot, whose lubrication could not be improved by any oil in existence. It is an ideal axis incompatible with the least idea of friction. Neither the air nor any other substance presents any obstacle, for the atmosphere turns with the Earth, of which it forms part, and beyond the aerial envelope there is nothing material in the space in which the great ball revolves. Since the Earth has no resistance to overcome, it must keep for centuries the impulse it received at the beginning of time. The inert mass was set in motion by the finger of the Creator, and it has been turning ever since it was moved by the Divine touch. It turns without any change of energy, without spending any of its motion, for which some day it will have to render an account to God who gave it. If we go back to the earliest history and compare astronomical observations of 2,500 years ago with the observations of our own days, science finds that during that period of 25 centuries the Earth's rotation has not changed by the one-hundredth of a second. As it turned in those distant times, when the Chaldean shepherds followed the movement of the sky in their night watches, so it turns to-day, and so it will turn in a future of which we cannot conceive the limit.

SIXTH LESSON

CELESTIAL POLES AND LATITUDES

1. SITTING on some great wheel in motion, an ant, if it could think with its little head, would consider itself motionless, since all the points of the machine which carry it along are always in the same situation with regard to itself. External objects, on the other hand, the ground, the trees, the sky, appearing in turn, would appear to the ant to have a motion opposite to that of the wheel. With the exception of objects placed opposite the axis, which would remain motionless, all the rest would seem to describe a circle around that axis, so that the real axis of rotation of the wheel would appear to the little animal to be the apparent axis of rotation of external objects. In the same way, the movement of the enormous terrestrial machine is beyond our view. We believe ourselves at rest, and we see space under the

false appearance of a spherical enclosure, turning round us from east to west so that each point of the sky seems to describe a circle round the axis of the Earth, produced indefinitely in both directions, except two points, which are kept immovable and correspond to the two ends of the axis prolonged until they meet the ideal vault of the skies. These two points are called the celestial poles. Each of them is placed on the celestial Globe, facing the corresponding terrestrial pole.

2. This furnishes the means of recognising in space the direction of the earth's axis, although that line is invisible, being purely imaginary. It suffices, indeed, to observe which star does not change its place and does not turn, or if there is no star quite at rest, to find out that which moves in the smallest circle. It is at the centre of that circle, the smallest circle of all, that the celestial pole, visible from here, is placed. It is the point towards which the axis of the Earth is pointing. A similar observation made in the opposite hemisphere would give us a second celestial pole which is hidden from us by the convexity of the Earth.

That star nearest the celestial pole which we can see is called the Pole Star. It is not quite immovable, but it describes an extremely small circle round the pole. In order to find it, we must take up a position on a fine night in open country facing that part of the sky which would be on our left if we were watching the sunrise. We can then see above the horizon a group of stars or constellation which is called the Great Bear, and that constellation is composed of four fairly bright stars disposed in a longish square and three others placed in an irregular row at one of the corners of the square. The Great Bear strikes the eye with its brilliance and

its size, for in that part of the sky where it is seen nothing can be compared to it, and on account of its position near the pole it is visible at any time of night. In turning about the axis it is sometimes higher and sometimes lower in the sky, but it never descends below the horizon in our latitudes.

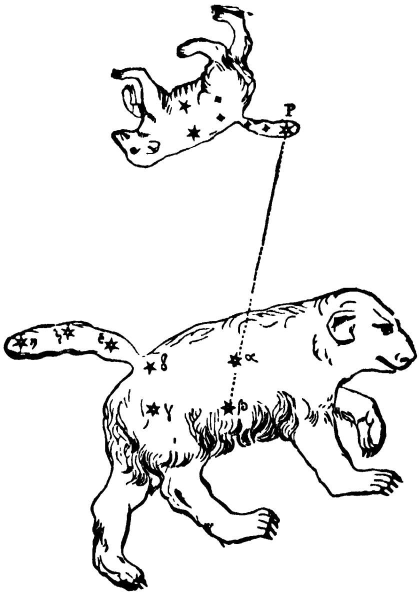


FIG. 26

3. Fig. 26 reproduces the shape of the constellation in question. Four stars form a part of the Bear's body, and the three others constitute its tail. As for the outlines of the animal itself, they are imaginary. In order to find their way among the multitude of stars, astronomers agreed to divide up the firmament into various regions to which they gave arbitrary names based upon a vague

resemblance to certain animals or objects. Each of these regions is called a constellation. The design on Fig. 26 shows that portion of the sky which in astronomy is called the Great Bear. This region contains several stars, among which only seven are remarkable, and these seven represent our picture, other stars not being shown. The name Great Bear applied to that region of the sky is, therefore, a simple convention. We must acknowledge that the name is badly chosen, for in order to include three prominent stars in the constellation it is necessary to give an enormous tail to the Bear, whereas the real animal has hardly any tail at all. The seven principal stars of the Great Bear are sometimes called Charles's Wain. In this case, the four stars in the square represent the cart with its four wheels, and the three others represent the harness. It is also called the Plough.

Outside the region of the Great Bear, sometimes above it, sometimes below, or on one side, according to the time of observation, there is seen another group of seven stars arranged in the same way as the first group, but less bright, and spread over a smaller area. Four of them form an irregular square, and three are attached to a corner of that square and form a tail. This new constellation is called the Little Bear. The tail of the Little Bear is always turned in the opposite direction to the tail of the Great Bear, and the star P (Fig. 26), which terminates the tail of the Little Bear, is the brightest of the group. Well, that star is the Pole Star, or the star which in our sky remains nearly motionless when the whole firmament is swinging in circular movement from east to west. It is, therefore, at a point quite close to that star that the Earth's axis encounters the ideal

celestial vault. In order to find the Pole Star when the Great Bear is known, we set about it as follows: The two extreme stars of the square of the Great Bear are called the "pointers." A straight line is drawn through these and produced along the sky until it encounters a star brighter than any in the neighbourhood. That particular star is called the Pole Star or Polaris. We may make sure that we have not made a mistake by examining whether the star thus found is at the end of the tail of a small constellation similar to the Great Bear and placed in an opposite direction.

At the opposite pole there are no remarkable stars. The nearest constellation is called Hydra. We need not occupy ourselves any further with that region of the sky, which most of us will never see.

4. The two poles of the Earth take their names from the constellation of the Bear. That which lies near the Pole Star is called the North Pole, or Arctic Pole, from the Greek word "arctos," which means a Bear. It is the pole which is nearest to us. The other, placed at the diametrically opposite end of the Earth is called the South Pole, or Antarctic Pole, meaning "opposite to the Bear." The poles are sometimes called Boreal and Austral respectively.

The direction of the Earth's axis and that of the apparent movement of the stars determines the four cardinal points—north, south, east, and west. The axis is in the direction north to south, and the apparent movement of the stars east to west. The determination of the four cardinal points is called "orientation." To verify an orientation in the daytime, one faces the rising Sun; the east will be in front, the west behind, the north to the left, and the south on the right. We might also

face the setting Sun. In that case, the west will be in front, the east behind, the north to the right, and the south to the left. For orientation at night, we face the Pole Star, or simply the Great Bear. In that case, the north is in front, the south behind, the east on the right, and the west on the left. We may also, of course, use a magnetic compass, the small steel needle of which points approximately north and south. On a map, north is always put at the top, south at the bottom, east on the right, and west on the left.

5. Is the Pole Star far away from us? What is, in general, the distance of the stars? The simplest use of astronomical instruments allows us to give a sufficient answer to this question for the moment. Telescopes, as their name implies, allow us to see the objects nearer than they are in reality. They transport them, so to speak, and place them within range of our eyes. Placed 300 yards away from us the page of a book would not only be illegible, but it could hardly be seen as a whole. With a telescope magnifying 600 times the page would be brought within half a yard of our eyes, and by this device its reading would become as easily feasible as if the book were actually under our eyes. But while the telescope brings the objects nearer it also makes them appear larger. That is, indeed, what happens with ordinary sight. An object seems the smaller the farther it is away. If it approaches, or if we approach it, it appears to grow. Distant mountains on the horizon seem like insignificant hillocks, while if we were near them we should be astonished by their bulk. At a distance of a few miles a large house appears as a small white point, but if we approach it sufficiently it resumes its true dimensions Thus the telescopes magnify the

stars, and the magnification increases as they are brought nearer. If thus by means of glasses a heavenly body is brought 100 time nearer it also appears 100 times larger.

6. Let us suppose that an astronomical telescope magnifying 100 times is pointed at the Moon. Immediately the lunar disk becomes a circle 100 times larger than it is when seen without a telescope. I assure you it is a sight of irresistible attraction to see the Moon enlarged 100 times and spreading out under our gaze its immense grey plains, its great volcanic funnels filled with darkness, and its jagged mountains with peaks flaming in the Sun. But all this does not concern us yet, we shall go back to it later. Let us only state that the Moon, brought 100 times nearer by the astronomical telescope, is enlarged in the same ratio.

Now let us point the telescope at the brightest star in the sky. The star, brought 100 times nearer to us, must surely appear 100 times larger and acquire at least the size of a span. But we are mistaken. Seen in the powerful instrument, the star remains quite a small luminous point of inappreciable size. It is in vain that it is brought 100 times closer, it is no larger. On the contrary, it appears smaller, for by its rigorous precision the telescope deprives it of the confused rays with which it is surrounded as seen by the naked eye. We may try a telescope which magnifies 1,000 times, 5,000 times, or even 10,000 times, it makes no difference. The star remains confined to its small dimensions, and all our efforts to magnify it fail. The cause can only be this: the star is immensely farther away than the Moon, which is enlarged in our telescope without any difficulty. Its distance is so prodigious that it does not make any difference to our vision to see it 10,000 times larger.

The Moon is a good distance from the Earth, we are all convinced of that, without any further information. Well, here is another distance, that from the Earth to the most brilliant star, which must be infinite in comparison with the distance to the Moon ; otherwise in bringing the star nearer with our instrument, we should definitely see it grow. And how much more must this be the case with fainter stars like the Pole Star, and others which we can barely distinguish ? We shall have to pile immensity upon immensity to obtain these inconceivable distances ; we must plunge the stars back into depths from which our imagination recoils. The Pole Star is therefore so far away that in comparison with the distance which separates us the Earth, in spite of its vast bulk, would only be a small pellet. It would be but a speck of dust. It would be practically nothing.

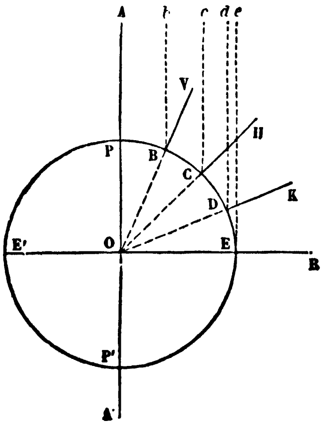


FIG. 27.

7. On account of the round shape of the Earth, we must, in order to see the Pole Star, raise our eyes above the horizon to a greater or lesser extent according to the position we occupy on the Globe. Thus an observer placed at the North Pole at P (Fig. 27) would see that star exactly overhead in the middle of the sky, on the axis of the celestial sphere. If the observer proceeds from P to B in what direction will he see the Pole Star ? He will see it in the same direction as before, because the amount of his displacement on the Earth is nothing

compared with the distance which separates it from that star; he will see it, in fact, along the line B*b* which points in the same direction as PA, and is therefore parallel to the latter.[1]

Strictly speaking, the two lines PA and B*b* meet in the end, because they both end in the Pole Star. But their meeting is made at such a prodigious height that we may, without any error in the result, consider them as not meeting at all, that is to say, as being parallel. Finally, the observer situated in B will see the Pole Star in B*b*, which is parallel to BA. But then, it is clear from the figure that the star does no longer occupy the top or middle of the sky, which we call the zenith, or the point directly overhead, which is also the point where the line BV would meet the sky,[2] but a position intermediate between the zenith and the horizon.[3]

[1] Two straight lines are called parallel when they are everywhere the same distance from each other. It is clear that straight lines can never meet, whatever the distance to which they are prolonged. Two opposite edges of a book, or a ruler, are parallel lines.

[2] We must remember that the vertical is the direction of the plumb-line. Produced indefinitely, the vertical passes on one side through the centre of the Earth, and on the other side through the summit of the celestial vault visible to the eye of the observer. The point where it meets that vault is called the zenith. The zenith is the point of the sky exactly above our heads, since in standing upright we keep a vertical position.

[3] We must understand by the horizon at the point B, the plane surface on the ground ideally prolonged in every direction. This ideal plane separates the half of the sky visible to the observer from the invisible half. It contains the circular line which limits the view in every country, and which is also called the horizon. If, in our diagram, we wished to represent the horizon at the point B, we should have to draw a straight line through that point touching the curve of the Globe, that is to say, a tangent. All that portion of the sky which was above that line, or rather above the plane which that line represents, would be visible to an observer placed at B. But the portion situated below would be invisible. All this is easily understood if we consider that the observer himself is only a point without appreciable dimensions,

For the observer, the Pole Star seems to have descended from the top of the celestial vault and got nearer to the horizon. The same remark applies to the point C. The Pole Star still seen along the parallel C*c* is distant from the zenith to the extent of the angle HC*c*, which is greater than the angle of the previous station. It is, therefore, still closer to the horizon. At D, the distance from the zenith is still greater, and, finally, at the equator E the observer sees the Pole Star exactly on the horizon along the line E*e* which grazes the surface of the Earth. If it goes beyond the equator into the other hemisphere, the observer ceases to see the Pole Star, which plunges below the horizon. The curvature of the Earth hides the view of the North Pole ot the sky; on the other hand, on crossing the equator, the constellations near the South Pole of the sky become visible, and they gradually rise above the horizon as the spectator approaches the South Pole of the Earth.

8. Let us sum up. At the North Pole of the Earth the Pole Star would be at the very top of the sky, directly over the observer's head. As he approaches the equator, the observer sees the star pass through the top of the celestial vault to the horizon; at the equator he would see it on the horizon itself, and beyond that he would cease to see it. Instead, he would see the constellations near the opposite pole, and they would behave in the same way, rising above the horizon or sinking, according as the spectator approached the South Pole of the Earth or receded from it.

We call the angle between the direction of the Pole

whose view is limited by the curvature of the Earth. In the language of Geometry we say that the horizon is a plane perpendicular to the vertical.

Star and the vertical at any given place the "zenith distance of the pole" for that place.[1] That angle is zero at the pole of the Earth itself, for then the Pole Star is just at the zenith in the vertical produced to the sky. At the equator it is 90 degrees. The height of the pole for any place is the angle at which the Pole Star appears above the horizon at that place. That angle is 90 degrees at the North Pole of the Earth. But it is zero at the equator. The zenith distance of the pole and the height or altitude of the pole amount together to 90 degrees, since together they form one-quarter of the circumference measured from the point overhead to the horizon.

9. The consideration of the zenith distance of the pole is of extreme importance. It serves as a basis for the construction of maps. If you are given a map to draw, you will find a model of it in your atlas. Your work is limited to the copying of a geographical design, much like any ordinary design, or you can simply trace it. But how were the first geographical maps made when there was no model from which to copy? The shape of a continent cannot be drawn like that of an object which can be seen as a whole. We roam over the soil with our vision imprisoned within a range of a few miles. We can hardly see the church tower of the neighbouring village, and yet we wish to draw the portrait of the Earth, to draw a map of the world, with the outlines of its continents and seas, as if from the height of the sky

[1] It would be more exact to say that the zenith distance of the pole is the angle between the vertical at a given place and the direction of the celestial pole. In order to fix our ideas we have supposed that the Pole Star is a prolongation of the terrestrial axis, which is not strictly true. But what we have said of the Pole Star applies to the celestial pole itself.

our gaze embraced the whole hemisphere. We are almost in the position of a blind person who would try to draw a sketch of a landscape; yet the difficulty, or, one might say, the impossibility, has been admirably overcome. Since he cannot overlook a considerable portion of the Earth's surface, not even a province, not even a parish, the geographer solves the problem indirectly. He asks the stars to indicate the position where he is placed; in order to draw the Earth, he looks at the sky. To trace an exact part of the Globe, it suffices to see the stars, the radiant starting-points of the world turvey. Let us consider for a moment the most elemensary features of this wonderful method.

10. In Fig. 28, the circle whose centre is at O represents the Earth. P and P′ are the two poles, AA′ is the Earth's axis, which produced upwards meets the Pole Star, EE′ is the equator. An observer is in B and he wishes to know the position of that point on the Globe. With that purpose, he measures with a theodolite the angle VB*b* between the line of sight of the Pole Star and the vertical VB indicated by the plumb-line. In other words, he measures the zenith distance of the celestial pole. Let us suppose he finds this angle to be 30 degrees.

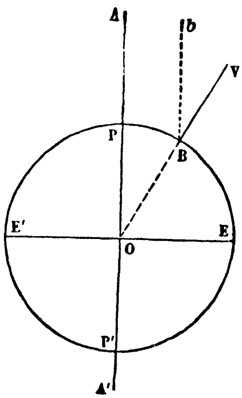


FIG. 28.

But the angle VB*b*, which the observer has just measured, is precisely equal to the angle BOP formed by the vertical at the observer's station and the axis of the Earth. A glance at the figure will convince you that this equality, which Geometry tells us is exact,

is due to the parallelism of the straight lines OA and B*b*.[1] By this ingenious device, the observer obtains the value of an angle, the apex of which is at the centre of

[1] This equality can be established in the following manner. Two straight lines as seen above are called parallel when they are always the same distance apart, and can therefore not meet. In order to trace two parallels on paper, we use a ruler and a set square. The set square is a thin board of wood of triangular form. The ruler being applied to the paper, the set square is placed in contact with it along one of its sides in the position CDH (Fig. 29). Then we trace the line CD with a pencil. Without moving the ruler, the set square is then moved into the second position *cdh*, and the new line *cd* is traced. The two lines thus obtained are parallel. The set square, in fact, slides in one piece along the ruler, moving away from its original position to the same extent in every part. Thus, its edge CD in every position it will occupy, and particularly in its position *cd*, is at the same distance from its first position in every part. Thus CD and *cd* are parallel.

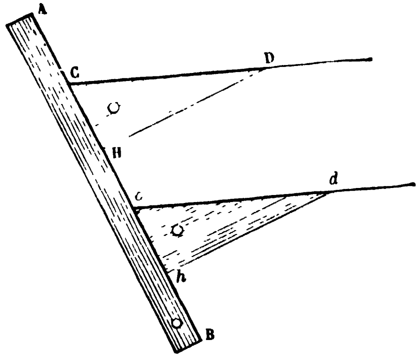


FIG. 29.

It is now clear that the angles DCB and *dc*B, formed by the ruler and the parallels, are equal to each other, since both are equal to the angle C of the set square. This is just that condition in which the angles BOP and VB*b* of Fig. 28 find themselves if we may imagine the two parallel lines OA and B*b* as given by a set square sliding along the ruler OV. If two straight parallel lines AB and CD (Fig. 30) are intersected by a third line HK, angles such as 1 and 2 are called corresponding angles, since they correspond to the same angle of a set square which, in order to trace two parallels, would have to slide along the ruler represented by the traversing line HK. The latter is sometimes called the *secant*, from a Latin word meaning "to cut." We can therefore say: *If two straight parallel lines are intersected by a secant, the corresponding angles are equal*

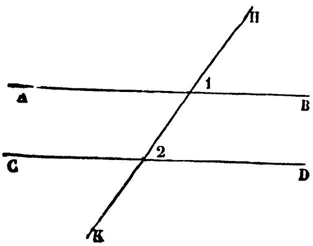


FIG. 30.

the Earth, with the same precision as if he had really taken his theodolite to the very centre of the Globe. We have already seen something similar to this in a orfmer lesson, and the exact measurement of an angle which we cannot see is therefore no longer astonishing.

Now we know the angle BOP between the radius and the axis of the Earth, but what does that angle teach us concerning the position of the observer ? It teaches us a great deal, for if it is an angle of 30 degrees, the terrestrial arc PB reaching from the pole to the observer is also 30 degrees, and the arc BE from the observer to the equator is 60 degrees, since the two angles together comprise one-quarter of the circumference. Let us indicate these degrees by lengths. A quarter of the Earth's circumference is approximately 6,000 miles. The arc PB being 30 degrees, and the arc BE 60 degrees, the former is one-third of 6,000 miles, and the latter two-thirds. Thus, the measurement of the zenith distance of the pole teaches us that the point in question is 2,000 miles from the pole of the Earth, and 4,000 miles from the equator.

Do you not see, already, that it is worth while measuring the zenith distance of the pole ? A mere glance at a theodolite, involving no difficulty, gives us distances which we could never measure directly.

11. To continue. By "latitude" we mean the distance of a place in degrees from the equator. That distance is measured on a great circle round the earth which passes through both poles. According to this, the latitude of the point B (Fig. 28) is 60 degrees, since the arc of the great circle OBE comprised between that point and the equator has been found to be 60 degrees. It also results from the preceding paragraph that in

order to obtain the latitude of a point upon the Earth's surface we need only measure the zenith distance of that point from the celestial pole. In deducting the angle thus found from 90 degrees, we obtain the latitude.[1]

We may note, finally, that in setting down the distance of a point from the equator, we must also specify whether the point is above or below that circle, whether it is in the northern or the southern hemisphere. Hence we have two sorts of latitude, northern latitude, for all the points situated to the north of the equator, and southern latitude, for the points situated to the south of the equator. The former is found by observing the zenith distance of the northern celestial pole, and the latter by making a similar observation regarding the southern celestial pole.

That being so, let us suppose that the observation of the pole has given a northern latitude of 26 degrees for some point on the Earth. We must now put this point exactly into its proper place on a terrestrial globe under construction. We must first make a cardboard globe to represent the Earth. We must pierce it with a needle representing the axis. The points where the needle pierces the cardboard are called the two poles. A great circle is traced around the globe at equal distances from the two poles; that is the equator. In order to place our point in position, we describe on the cardboard globe a great circle PAP′ passing through the two poles (Fig. 31); and on that circle, reckoning from the equator, we count 26 degrees, as shown in the diagram. Through the point A thus obtained we describe a smaller circle

[1] The latitude of a place is also equal to the height or altitude of the pole above the horizon of that place. That is evident because the altitude of the pole is 90 degrees minus the zenith distance.

parallel to the equator. We are certain that the point to be placed on the globe must be found somewhere on this circle, either in the portion visible in Fig. 31, or in an invisible portion of it, for all the points of this circle have 26 degrees of northern latitude, and are 26 degrees to the north of the equator. Thus, by finding the latitude of the various points on the Earth, we can find exactly on what parallels these points are situated, whether above or below the equator, and the problem of faithful representation of the Earth is half solved. In order to find the dwelling of a person in a great city we must know his address, we must know the house and the street. In the same way, for placing points on the Earth on the terrestrial globe, we must know first of all their street, that is to say their parallel of latitude which is given by the observation of the celestial pole. But that is not enough, we must also know their number, that is to say, their place on the parallel of latitude, and how to get this will be taught in the next lesson.

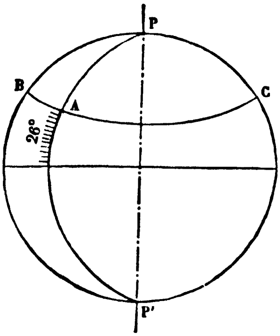


FIG. 31.

SEVENTH LESSON

HOUR AND LONGITUDE

Apparent revolution of the Sun, 1.—Noon and the meridian, 2.—Terrestrial clock-work and the immutable clock of the sky, 2.—A watch is fast or slow when taken out of its meridian, 3.—The hour on a desert island, 3.—Variations of the length of shadows according to the altitude of the Sun, 4.—Shadows are shortest at midday, 4.—Determination of noon, 4.—The twenty-four hour meridians, 5.—Succession of the hours over the Earth, 6.—The prime meridian, 7.—Chronometers, 8.—Completion of the Earth's meridian, 8.—Longitude and latitude, 9.—A voyage round the Earth along the meridian, 10.—Table of hours at a given moment, 10, 11, 12.—The great workshop of the Earth, 12.

1. THE Earth turns in face of the Sun. In 24 hours it shows to the Sun all its sides, which receive from it in turn their daily rations of heat, light, and life. To an eye which, from the depths of space, embraces the Earth and the Sun in the same perspective, the latter would appear as an enormous globe following the sky with its luminous rays; the former would appear like a little ball half illuminated, half dark, turning respectfully before the glory of the sovereign star. A grain of sand, dancing before a great white-hot cannon-ball, such is the Earth in face of the Sun. To us, the appearances reverse this relation. The Earth, whose volume seems above all comparison, since in the small part accessible to us it shows itself in its real dimensions, is naturally regarded as immovable on its immense foundation, and the Sun, diminished by distance and reduced to a flaming disk,

traverses the sky to distribute its rays over the Earth. It seems to arise in the east in the morning mist, it gets hotter and brighter until it arrives at the summit of the sky at noon; then, descending again from the heights of the celestial vault, it plunges in the west into the purple evening, to continue its career on the other half of the sky, to warm other countries and to come back to us in the morning. This apparent voyage is quite a simple matter, if we consider that the Earth, in turning on its axis from west to east in 24 hours, presents to the Sun its various regions in turn, so that each of them sees the Sun on its eastern horizon, then in the height of the sky, when rotation has brought it directly under its rays, and finally on the western horizon, just as if the Sun itself revolved from the east to the west round an immovable Earth. Whether the Earth turns from west to east in face of the Sun, or whether the Sun revolves in the opposite direction round the Earth at rest, the results are the same, and, indeed, it makes matters easier on some occasions if we conform to appearances. We shall, therefore, say that the Sun revolves from east to west, but we must not lose sight of the fact that this is simply a concession to our habits of expression.

2. It is clear that the Sun can only illuminate half the terrestrial Globe at a time. In that illuminated half it is day, while it is night in the other half. At noon the Sun reaches the highest point of its course, and occupies the middle of a semi-circle described upon the horizon. Let us imagine an ideal plane passing through the vertical of the place where we are, and through the axis of the Earth. If we supposed it to be indefinitely prolonged above that point and below through the Earth and surrounding space, it will also divide the sky into two equal

halves. It will, in particular, divide the celestial vault over our heads into two halves between which there will be the midday Sun. Hence the name of meridian, from a Latin word meaning midday. This plane traces on the surface of the Earth an imaginary great circle which passes round the Globe and through the two poles. This is also called the meridian. According to these definitions, it is noon at any place when the Sun is directly situated over the meridian passing through that place, or, which comes to the same thing, when it reaches the plane of that meridian ideally extended into the sky. All points situated on half of the same meridian in that hemisphere which faces the Sun have their noon at the same moment from one pole of the Earth to the other. All the points situated in the opposite hemisphere, on the other half of the meridian, register midnight.

A fundamental question now remains to be solved: to find for any given place the precise moment when the Sun reaches the plane of the meridian. In other words, to find the instant of midday or noon. Your answer will be quite ready. You will say, that is very simple. All we need is a good watch, and when the hand arrives at 12 o'clock the sun will pass through the meridian. I agree, if the watch is perfectly correct, but we must notice that all our watches and clocks follow, as well as their imperfections permit, the invariable clock of the skies. They measure the time according to the uniform movement of the Earth about its axis, or, if you prefer it, according to the apparent revolution of the sky round us. A watch does not give the true hour unless it is regulated by the great celestial clock which distributes the hours with inflexible uniformity; it must follow with the movement of its hands the regulating movement

of the Sun, so that an astronomical observation gives the hour to several watches, even to yours, although you do not consult the sky but another watch or clock, which is regulated by the Sun.

3. A watch or clock does not indicate the true hour except for the meridian of the place for which it has been regulated. You may start from Lyons, I suppose, with an excellent watch set to the hour. You travel towards the east across Switzerland to Austria, and you soon find that the clocks of the towns where you arrive are more and more in advance of your watch as you get farther east. The clocks show half-past 12, 1, 2, 3, etc., while your watch will only show 12. That is quite natural. Being farther east, these countries see the Sun rising earlier, and reaching the middle of the sky earlier. Their noon is therefore earlier than that of Lyons, and their clocks are necessarily in advance of your watch, which gives the hour not of the place where you are, but of the place where you came from. In going from Lyons towards the western provinces of France we should make the opposite observation. The clocks would be slow in comparison with the Lyons watch by half an hour at the most, because your displacement towards the west would not be considerable. But once the Atlantic is crossed, we should find that in the United States of North America it is six, seven or more hours behind. In some points, they would not have daybreak even when the Lyons watch showed midday. This lag is conceivable if we consider that the United States are very much farther west than Lyons, only getting the Sun a long time after the town where your watch was regulated. Thus a watch only shows the exact hour for which it has been expressly regulated, or rather for

that particular meridian. Outside that meridian it is in advance or slow, according to its westward or eastward displacement from the original meridian. It must be regulated by the clocks of the new countries.

Let us do more. Let us traverse the seas all round the Earth. Let us land on an unknown island visited by man for the first time. What time is it, if you please, you there, with the Lyons watch ? You draw the precious instrument out of your pocket, but without avail. The exiled watch does not know the hour. It shows 5 o'clock, and yet the Sun, in all its force, is just overhead. Whom shall we ask for the time in this place, where there is no society except the flocks of birds which are stupidly digesting on the edges of the cliffs ? We shall ask the time of the world's clock, that clock which need never be wound up. We shall ask it of the Sun by noticing the instant at which it passes the meridian. Once we have got that moment, the watch will be regulated and we shall know the time so long as we remain in that place.

4. The observation of shadows will tell us the instant at which the Sun passes through the meridian. We have all observed how the shadow which we throw on the ground varies in length according to the hour of the day. Everyone remembers the midday shadow which gives our image the grotesque appearance of a dwarf, and the evening shadow which stretches it out to that of a lanky giant ? These different lengths correspond to the position of the Sun. The closer the Sun comes to the horizon the more oblique are its rays, and the longer is the shadow. When the Sun is at the height of its course at noon, the shadow is as short as it can be. In order to show this, let us use a diagram. Let us represent

the course of the Sun upon our horizon by the semi-circle AHB (Fig. 32), and the horizontal ground by the line AB. Let us place a vertical rod in the ground at OK. When the Sun is at S its rays graze the top of the rod along the line SD, producing the shadow OD. When it passes to S′, the shadow becomes OD′, and from S″ it gives the shadow OD″. We therefore see that the shadow diminishes in length as the Sun rises higher in the sky. When it arrives at the top of its course in H, the shadow according to the diagram should be zero, and that would be the case indeed if the Sun, as shown, passed directly over the vertical rod. This never happens in our countries, as the Sun is never in the vertical itself. The diagram, necessarily traced on one plane, the plane of the paper, is therefore faulty. We must correct it in our minds, and suppose the rod to be outside the paper a little in front of the circle followed by the Sun. We can then understand that there is a shadow at the moment of noon, but that shadow is the shortest of all. In certain regions of the Earth, and at certain times of the year, as we shall see, the Sun passes just over the vertical, and then the shadow of the rod placed vertically is really nothing at noon. But let us leave this particular case aside, and recognise that the shadow is as short as possible when the Sun has attained the summit of its course.

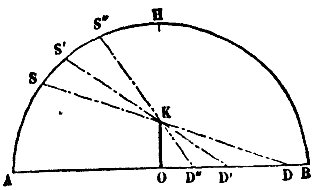


FIG. 32.

Let us apply these principles to determining the moment of noon. On a horizontal plane, such as a big slate carefully levelled, we fasten a needle in the precise direc-

tion of the vertical. Illuminated by the rays of the Sun, that needle will project upon the slate a shadow which will be very long and point towards the west at sunrise, but will get shorter and shorter until noon, and then lengthen out again, pointing to the east. It will, at certain hours, equally distant from noon, reach the same length as it did in the morning. Let us watch for the instant at which the shadow ceases to become shorter, and commences to lengthen out. At that instant, the Sun has reached the summit of its course and is traversing the plane of the meridian. It is then exactly noon, and the direction of the shadow gives the direction of the meridian.

5. A meridian, as we have said, is a great circle which passes round the Globe and through the two poles. It is the result of a cut through the Earth made by an imaginary plane, which passes from the vertical of the place and through the Earth's axis. The number of the meridians is infinite, because we can always suppose one to pass through any point of the Earth we may wish. It is true that all points which are directly north and south have the same meridian, but all points lying in a different direction have a different meridian. On terrestrial globes a certain number of these circles are traced, each fixed at the pole and spread out to envelop the sphere, and to meet again in the opposite pole. We may compare them to the ribs of a melon which pass from one pole to the other, from the stalk to the bud at the top.

Let us imagine the Earth traversed from one pole to the other by 24 semi-circles, which each represent the half of a complete meridian, and are equally distant from each other. On account of its daily rotation, the

Earth presents these 24 semi-circles to the Sun's rays one after the other. The half-meridian exactly facing the Sun is at noon, the other half in the other hemisphere is at midnight. At the same moment, the half-meridian to the west is only at 11 o'clock, since it will be vertical under the rays of the Sun one hour afterwards. A third shows 10 o'clock, and a fourth 9 o'clock, and so on, with a difference of one hour for each of the 12 semi-circles of the western hemisphere. On the other hand, the half of the meridian preceding the one we started from shows 1 o'clock in the afternoon, since it is an hour ago that it was vertical under the Sun. The next one shows 2 o'clock, and the others 3, 4, 5 o'clock, and so on.

6. Fig. 33 completes the demonstration. The Sun, which must be supposed to be at a great distance from

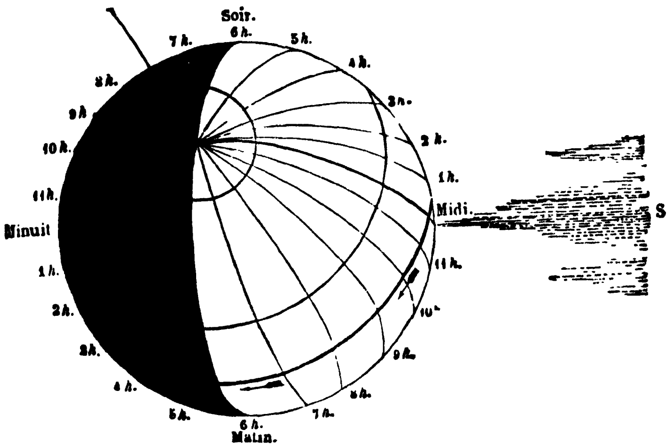


FIG. 33.

the ball here representing the Earth, is now in the direction S. It illuminates half the Globe, and leaves the other in darkness. A single ray is shown falling vertically

on a certain meridian. All the points situated on that meridian towards the Sun have now midday, while midnight reigns in the opposite hemisphere, where it is dark. The rotation of the Globe about its axis, which is in the direction indicated by the arrows, will take the following meridians marked 11*h*, 10*h*, etc., and so on, under the vertical rays of the Sun. But for the present those meridians have not seen it at its greatest height, and therefore the day is less advanced. The nearest, denoted by 11*h*, will arrive under the vertical rays of the sun in one hour's time, and will therefore be an hour before midday, or what we call 11 o'clock in the morning. The next few meridians show 10 o'clock, 9 o'clock, and so on, because they will be facing the Sun in two hours, three hours, etc. As regards the meridians denoted by 1*h*, 2*h*, 3*h*, they have already passed, one, two, three hours ago, under the direct rays of the Sun, and the rotation pushes them farther towards the night. For the first of these, it is 1 o'clock in the afternoon, for the second 2 o'clock, for the third 3 o'clock, etc. In fact, it is one hour, two hours, or three hours ago respectively that they have passed under the midday Sun. Further explanation is unnecessary.

7. In Fig. 33 we have marked 24 half-meridians with a difference of one hour between each. Since they comprise the whole circuit of the Globe, the distance between them is one 24th part of the circumference, that is to say, of 360 degrees. There are, therefore, 15 degrees of the complete circuit of the Earth between each one and the next, if we count those degrees on the equator, which is the circle defined by the arrows at the base of the diagram. These 15 degrees of the circumference of the Earth correspond to one hour of time. This will enable

us to complete our representation of the Earth. We have already seen how the zenith distance of the pole gives us the latitude of a place and shows us on which parallel of the equator on the terrestrial Globe that place must be found. We can now locate all the places, so to speak, as regards the "street," or the parallel of latitude. We must now find the number or the point occupied on that parallel, and this is done by a comparative study of the hour. Let us trace on our cardboard globe a meridian which serves as a starting line. This meridian is entirely arbitrary, but for the sake of uniformity in geographical works it has been agreed to choose the meridian which passes through the observatory of Greenwich. It is called the prime meridian, or the convention meridian. On all maps it is numbered zero. Let us suppose that this is the meridian PAP′ of Fig. 31 (Lesson 6).

8. We start from Greenwich with an excellent clock regulated for that meridian, a clock which goes for a long time without having to be regulated, and which is always wound up before it stops. It is called a *chronometer*, which means a "measure of time." It shows the hour of the place from which it starts, and not the hour of the place to which it is brought. We have now come to a point which we wish to inscribe on our terrestrial Globe. By the method of observing the length of a shadow, or by more precise methods which cannot here be described, we determine the instant at which it is noon at the place. Now at that instant the chronometer indicates 10 a.m. Greenwich time. What does that mean? It means that the place where we are is on a meridian twice 15 degrees, or 30 degrees, east of the meridian of Greenwich, because it is noon two hours

before it is noon at Greenwich. The zenith distance of the pole at the same time gives us 26 degrees of northern latitude. That is all that is required to inscribe this point on the earth in its proper position on our terrestrial Globe.

The latitude furnishes us the parallel BC (Fig. 34), somewhere on which the place must be situated. Then if we start from the convention meridian PAP′ and measure 30 degrees towards the east as indicated by the difference of hours, and draw a meridian PLP′ through the 30th degree, the place considered must be situated at L, the point of intersection of the parallel and of the meridian in that place.

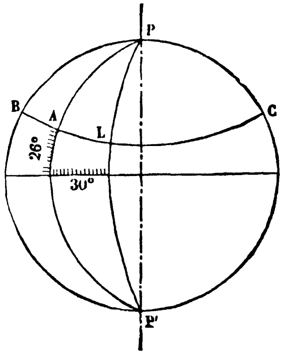


FIG. 34.

It is obvious that if at the instant of noon the chronometer showed 2, 3, or 4 hours in the afternoon, that would mean that the meridian of the place considered is on the west of the first meridian at a distance of 2, 3, or 4 times 15 degrees. Then, instead of counting these degrees on the equator from left to right (Fig. 34), we should count them on the opposite way, from right to left, always, of course, from the prime meridian of which the chronometer gives the time. We also see that if the difference of time comprises hours, minutes, seconds, these would easily be translated into degrees, minutes, and seconds of arc, and so we should have all the precision necessary in geographical maps. In order to map the Earth point by point, two instruments suffice, the watch and the theodolite. As I have said, a geographer bent on

mapping the earth consults the sky. Similarly, a navigator guides himself by means of those celestial signposts, the Pole Star and the Sun. He asks them for the hour and the height of the pole in order to know the point which he occupies on the deserted face of the ocean.

9. Longitude is the distance in degrees between the meridian of the place and the prime meridian. It is either westerly or easterly. It is easterly if the place is on the east of the prime meridian, and westerly if it is to the west. In the former case the place considered has its noon in advance of Greenwich, and in the second after Greenwich. Longitude is counted on the equator, and if not on the equator then along a parallel as in maps, which only include a small portion of the Earth It varies both east and west of the prime meridian from zero to 180 degrees. The zero corresponds to the half-meridian passing through Greenwich Observatory. The 180th meridian is the half-meridian which is opposite in the other hemisphere. Longitude is obtained with the help of a chronometer.

Let us remember that the latitude of a place is the distance in degrees of the parallel of that place from the equator. It is northerly, or southerly, according as to whether the point considered is to the north or south of the equator. It varies from zero to 90 degrees, and is reckoned along the meridian. It is obtained by measuring the zenith distance of the nearest celestial pole.

The reckoning of longitude and latitude comes to us from the Romans. They only knew a small portion of the Earth, that which surrounds the Mediterranean. That portion being longer in the east and west direction, or the direction in which meridians are counted, than in the north or south direction, where latitudes are

reckoned, they called the distance counted along the greater dimension of the world then known longitude or length, and the distance counted along the smaller dimension latitude or width. At the present time we must no longer attach the ideas of length and width to longitude and latitude respectively. The Earth is round, and its dimensions north and south equal its dimensions west and east, apart from the very feeble depression at the pole.

10. The network of meridians and parallels on the map of the world is now no longer an enigma to you. You know that these imaginary lines are a sort of scaffolding of the geographical edifice, since they serve as a basis for tracing the configuration of the Earth. Once that edifice is constructed most of the lines are suppressed so as not to overload the design, but a certain number of meridian parallels are always retained even on the smallest map, since they give us information of great interest. Take a map of the world and follow these meridians, and by the aid of those lines, which told you nothing and yet know so much, we can make a marvellous voyage. We shall be able to know the hour which strikes at present in any place we wish, and we shall be able to watch the Earth as it revolves here in bright sunlight, there in the first rays of the dawn, there again plunging into darkness or illuminated by the last red rays of sunset.

At the present moment it is, let us suppose, noon at the Greenwich meridian. It is also noon over all England and France, and within half an hour of noon for the extreme eastern and western points of these countries. It is noon, the hour of greatest sunshine, and of our midday rest. Follow me on the world map towards the east. The Crimea is in the meridian number 30, it

is 30 degrees of eastern longitude. The Sun, which passes from east to west at the rate of 15 degrees per hour, has therefore passed across the height of the sky in the Russian peninsula two hours before reaching the meridian at Paris. For the Crimea it is therefore 2 p.m., since the hour is the same from the one end of the half of the meridian to the other, and it is also 2 p.m. for Egypt, 2 p.m. for the fellah who, at that moment in the shadow of some palm-tree, draws water out of the Nile with a leather bucket and irrigates his field of onions. It is also 2 p.m. for the Kaffir, who rubs himself with rancid butter and braves the attack of the rhinoceros and the venomous bite of the mosquito. It is 4 p.m. for the miner of the Ural mountains, who, under the 60th meridian, digs in the granite for the vein of gold and platinum. A sad business, that of this poor seeker after gold! Then I see the grass-grown and salty plains of the shores of the Lake of Aral. The moment is near when the Tartar shepherd will milk his mares to prepare his drink of soured milk.

On the banks of the Ganges, in longitude 90 E., it is 6 o'clock. The west reddens where the Sun is about to set.[1] The cayman from its lair of rushes raises its green eye to the heavens and turns its hideous head to take a last look at the radiant day star, the light of the world that shines upon the reptile as it does upon man, the elephant trumpets a salute, and the tiger snarls.

[1] It is here supposed that the Sun rises at 6 a.m. and sets at 6 p.m. This is only the case at the spring and autumn equinoxes, that is to say, March 22nd and September 22nd. At other times of the year sunrise and sunset take place earlier or later, but this does not disturb the distribution of the hours. When it is noon at Greenwich it is always 6 p.m. at the mouth of the Ganges, whatever may be the time of sunset.

11. Now, in the neighbourhood of the 120th meridian, an immense city is seen where the people have supped by the time we have lunched. It is Peking, the capital of China, wrapped in the obscurity of 8 o'clock in the evening. On its public squares the crowd walks about gaily by the light of coloured lamps, some with long pigtails reaching from the head to the heels. The tom-tom and the bamboo pipe draw the ninnies to the sight of the open-air marionettes. Behind this window with its muslin curtain painted with a dragon we may see a mandarin dining late and enjoying his soup of swallows' nests, or dexterously handling his ivory chop-sticks instead of a knife and fork. We may even surprise him putting a grain of opium into his pipe and smoking the infernal drug. But we will be discreet and time presses. Let us pass on. What do I see down there at the same hour nearly at the other end of the world? On the outskirts of the wood half a dozen brutal savages dance about a dying fire and search the ashes before going to sleep to find the last pieces of a nest of white ants which has been grilling for the evening meal. They are Australian natives, poor derelicts of the human family. In Kamchatka the night has fallen some time ago. It is after 10 o'clock, and nearly everyone is asleep. Yet in spite of the darkness I seem to see a hovel half-buried in the soil. Its chimney smokes, and therefore somebody is awake. A bear has been caught in a trap, or a fish in the net, and so they make merry through the night. Over the fire, which is fed with fat, sides of bacon and jugs of juniper rum are festooned. A little farther along, under the 180th meridian, we reach the extreme east of Siberia, the Behring Straits, where it is midnight. It is rather less than midnight in New

Zealand. Silence! Do not let us awaken the people sleeping here, quaint savages covered with tattoo marks.

12. We are now on the other half of the Greenwich meridian, in the centre of the Pacific Archipelago. Let us pass by these islands which sleep profoundly under the shelter of cocoa palms. Let us cross the great ocean where we find here and there a few luminous points representing ships in motion, and let us proceed to North America. In California, at the 120th degree of western longitude, it is 4 o'clock in the morning. San Francisco, a city of dollars and revolvers, is still asleep. If it were daylight I should show you in the mountains of the interior something more remarkable than the gold nuggets picked from the Californian gorges. I should show you a group of enormous trees, patriarchs of the world of plants, which bear the weight of 5,000 years of existence on their venerable heads. But unfortunately the night is as yet too dark. At the mouth of the Mississippi it is 6 o'clock in the morning and the Sun is rising. The pink heron, standing on one leg on the top of the river bank, sees the glorious disk rising from the bosom of the ocean and gives a cry of joy as it flies to meet it. More to the north, near the Great Lakes of Canada, the elk is belling towards the rising Sun in the thicket white with hoar-frost. Farther south, in the first rays of the Sun, the porpoises gamble in a joyous dance in the waves of the Chilean seas. On the western coast of Greenland it is 8 o'clock in the morning for the Esquimos. Since sunrise the valiant hunter with his sledge drawn by a dozen dogs has been roaming over the snowy plain in pursuit of sable and blue fox. It is 8 o'clock in the centre of Brazil, 8 o'clock for the humming-bird which finds the heat of its climate already too much, and retires

into the shades of the wood after its excursion among the flowers, in the company of butterflies which are less beautiful and less agile than itself. It is 10 o'clock in the middle of the Atlantic, and it is midday for us. But the Globe turns and the aspects change. Those who slept awaken, and those who were awake go to sleep. Those who were working are at rest, and those who were resting are at work, and thus, in the great workshop of the world, activity never ceases for a moment.

EIGHTH LESSON

ILLUMINATION OF THE ATMOSPHERE

1. THE fresh clearness of the morning rises in the east ever more limpid and more beautiful, and drives before it the shadow of night like a veil that is lifted. A gold and purple fringe borders the eastern edge of the sky. The clouds turn crimson. A flash arises, and the air trembles before the radiant apparition of the Sun mounting up on the horizon. It rises in sovereign power, becoming every moment more and more luminous. Its rays plunge from the high peaks above into the plains, and from the plains down into the valleys and drive away the grey mists of morning. The fog in the valleys climbs the neighbouring slopes as if pushed up by some invisible hand. It is torn by the edges of the rocks, it is divided into wisps, and dissolved in the warm air. It is the hour of the joys of awakening, when the sparrow twitters in

the leafage. It is the hour when the beetle with the golden wings hums in the hawthorn; the hour when the pendent flower straightens and unfolds to the smile of the day. It is the hour when the soul, the divine flower, arises also, and turns its fresh thoughts to God, at whose feet the Sun swings in the abysses of the Infinite.

At noon, the proud day star arrives at the summit of its course, at the height of the serene solitudes of the sky. At that moment space, inundated by vibrant life, is filled with an aureole before which all the concentrated brightness of molten metal would pale. At the centre of this glory an orb shines in steady splendour. Every eye braving that great blaze would be blinded forthwith. An implacable glow descends from it which burns our eyelids, which barely leaves its mantle of shadow on the tree, and which makes the sand of the road twinkle like the fragments of a broken mirror. A flood of heat descends from it which hardens the ground like a brick, penetrates our skins and threatens to dry up the blood in our veins. The great midday Sun sets the cricket chirping on the olive-tree and delights the lizard in its burrow. It browns our faces, but it ripens the harvest, too. It humbles us by its glory, but it is the father of life. Poplars stretch higher to see it, and the moss creeps from the crevice of the rock.

The evening comes. Like a grindstone of red-hot iron, the declining day star descends to the horizon through the blaze of the western sky, and its slanting rays throw upon the waters a glow as of live coal. It reaches the edge of the sky, and sets for us, while it rises for another hemisphere. It plunges behind the farthest hills. It is going, it is gone. May it come back to us to-morrow

as radiant as it was to-day! And may it never be extinguished, for that would be the end of all things!

2. In order to produce daylight, the blinding brightness of the Sun requires an intermediary. The Sun, no doubt, is the sower of light, but by itself it cannot give what we call daylight, as we shall see. Remember the ray of sunlight shining through a hole in a shutter into the darkness of a closed room. That ray, as you know, forms a luminous band in which motes of dust suspended in the air float and twinkle. If we raise a new cloud of dust the band of light is brightened at once, while it grows fainter as the dust settles down. Thus the beam of light is more or less brilliant according to the amount of dust it encounters. Yet that dust is not the cause of the light. It only serves to make it visible from the dark corner where we are standing, and whither no light would penetrate otherwise. Each of the particles, in reaching the beam of sunlight, lights up and becomes a bright point which, like a small mirror, transmits to us the light which falls upon it. If there were no dust in the path of the beam, the latter would not become quite invisible from our corner, but it would become incomparably less bright. I go further, and say that it would become quite invisible if there was nothing at all in its path. But there always is something. There is matter, there is air. And air can be regarded, from our point of view, as dust reduced to extreme fineness. And it is air which makes the beam visible in the absence of all coarser matter. It is understood, of course, that in the absence of all dust, and even of all air, the beam of light would be visible if, instead of looking at it from one side, our eyes were in the direct line of it. It follows that light is only visible

in two cases: when it reaches our eyes directly, and when we look at any matter illuminated by it.

3. The aerial ocean which we call the atmosphere is wrapped round the Earth, and its feeble coloration produces in the daytime the appearance of a blue vault. Every portion of that enormous mass of gas is illuminated by the Sun as are the motes in the sunbeam. It disperses the light falling upon it and transmits it to us by reflection, so that the illumination, instead of coming solely from its original source, the Sun, descends upon us tempered and uniform from the whole sky. We call this atmospheric luminosity "diffused daylight," while we call that which arrives to us from the Sun direct sunlight. In our houses, in the shade and under a cloudy sky we are illuminated by the luminosity of the air, by diffused daylight, while under the rays of the Sun we have direct sunlight. The air is then the chief disseminator of daylight. Wherever it goes it takes with it in the form of diffused light a reflection of the Sun's rays which it has received by multiple reflections in the atmospheric mass. In the absence of air there would be no light, except directly in the rays of the Sun. There would be no diffused light, and whatever could not receive the rays of the Sun either directly or reflected by the ground would be in complete darkness. The line of demarcation between light and darkness would be quite sharp. On the one side there would be daylight, and on the other side there would be night, without any transition. One step forward, or one step backward, would take us into the region of shade or into the region of light. In the morning, without any preparation, the light of day would succeed the darkness of night. The first light would burst from the east with a terrifying suddenness.

Hardly would the extreme edge of the Sun have disappeared under the horizon in the evening when darkness would set in as suddenly as it does in a room when the lamp is blown out. In our own dwellings on every side except that facing the Sun there would be complete darkness at noon. A shady corner would no longer be in dull daylight, but in complete darkness. Terrestrial objects deprived of their envelope of luminous air would have brutal lines of demarcation between the portions illuminated direct and those not illuminated, as in a fantastic black-and-white sketch. The sky would lose its blue colour and become intensely black. On that dreary background the Sun would blaze with a rayless intensity, and the stars would be as visible at midday as they are at midnight.

4. The stars visible at noon! Stars in the sky in the daytime? Yes, and it is just the daytime illumination of the atmosphere which prevents our seeing them. Here we must give some explanation.

Let us take a live coal from the fire. Seen in the darkness it shines with the full brightness of incandescence. Taken into full daylight it does not shine so brightly. It seems to be cold, and we should seize it fearlessly with our fingers if we had no warning concerning its heat. We take it back into the darkness. It revives and resumes its brightness. It is as brilliant as ever, though as soon as we take it back into the daylight it still appears to be extinct. The flame of a candle gives rise to similar observations. In the dark it gives a bright light, but in the sunshine it is hardly visible. There is no doubt that in daylight as well as in darkness the live coal and the flame of a candle preserve the same brightness; and if that brightness seems to pale and even become impercep-

tible in sunlight, it must be due to the fact that the eye under the influence of the penetrating daylight is no longer sensible to feeble lights. Our sight, like the rest of our senses, allows an impression to pass without effect under the influence of a more powerful impression.

Now it is through the luminous depths of the atmosphere bathed in sunlight that the stars send us their rays in the daytime. We can immediately see from our preceding experiments what is bound to happen. Veiled by the luminous curtain of the air they will remain invisible, since their feeble brightness is drowned in the splendour of the air. But they resume their visibility as soon as the air above us has become dark because it no longer receives the Sun's rays. Brighter at night and less bright in the day than the atmospheric ocean through which we see them, they appear and disappear periodically by contrast, although the sky is always full of them.

5. The firmament is therefore never deserted. If the Sun makes a solitude, it is but an apparent solitude occasioned by the illumination of the atmosphere. In order to perceive the daylight stars, those which occupy the sky in the daytime, it suffices that the eye is somehow protected from the brightness of the atmosphere. At long intervals we witness an eclipse of the Sun when the Moon, dark and invisible, intervenes between us and the Sun and intercepts its rays much as we could stop the rays of a lamp with our hand. Behind that celestial screen the portion of the atmosphere above us is momentarily deprived of Sun-rays. The illumination of the air is stopped, and a crowd of stars whose presence we could not have suspected show themselves as they do at night, only to disappear when the Moon moves on and no longer throws its shadow.

Other circumstances which we can control ourselves also show this strange spectacle of a starry sky in the presence of the Sun. The luminous layers of the air produce, as we have seen, the invisibility of the stars in the daytime. We can, however, perceive at least the brightest of them by rising into the higher regions of the atmosphere. For since the mass of air traversed by our sight diminishes in brightness as its depth decreases, the sky must at a certain height grow sufficiently dark not to obscure the stars entirely as it does on the ground. And, indeed, it has been found that on the top of the highest mountain the sky appears very dark blue, nearly black, and that on that darkened background the stars are seen in broad daylight, though not indeed all of them, but only those whose rays are able to rival the remnant of the atmosphere. Even the faintest stars would appear if the observer could penetrate to the extreme limit of the atmosphere. He would only have to turn his back to the Sun to see them shine in the black space in full sunlight as if they were fixed on black velvet.

6. Freely directed at the sky our gaze embraces in the daytime a great luminous expanse which makes it impossible to see the stars. If the field of view could be greatly restricted only a small portion of the brightness of the air would reach the eyes, and then the brightness of the stars could predominate sufficiently to become perceptible. It is said, indeed, that by looking up through a factory chimney, or from the bottom of a shaft, persons with good eyesight are able to distinguish some stars in the narrow region of sky within view.

The best means of circumscribing the field of vision and protecting it from the brightness of the air is to

employ an astronomical telescope. The instrument has two advantages. In the first place its long tube plays the part of a chimney, or shaft, in restricting our vision to a small portion of the sky. In the second place, its optical lenses gather up the light of the stars and strengthen it by concentration. With an astronomical telescope, no matter at what hour of the day observation is made, whether morning, noon, or night, the stars show themselves in the sky as numerous as they are at night. Our conviction is complete. If the day sky is seen without stars it is because of the illumination of the atmosphere. In reality it is as starry as the night sky. Ceaselessly, on account of the revolution of the Earth about its axis, new stars follow each other on the eastern horizon, rise in the sky and sink towards the opposite horizon. Every twenty-four hours the same thing happens in the same succession.

7. On a dark night raise your eyes to the heavens. What do you see there besides the stars? Nothing. Everything is as black as ink. But will you believe me when I say that at this very moment those black depths are inundated with light, that those terrible dark spaces are filled with floods upon floods of sunlight? Will you believe me when I say that in the middle of the night the Sun throws into our sky, up there where we see nothing, rays as bright as at noon? No, you will not believe me because it seems impossible. Well, then, I shall prove it.

The Earth, as I have said before, can be compared with a grain of sand illuminated and heated at a distance by a white-hot cannon-ball. The Sun is the cannon-ball. It sends into every direction of space its light and its heat. The Earth, amidst this radiation, receives its

modest part just as a blade of grass in a storm receives its drop of rain. Where, then, do the other Sun-rays go? They go here and there to vivify other worlds, they spread broadly through the void into fields of infinite space. The Earth is enveloped by the Sun's rays, it swims in the luminous flood which the day star untiringly pours into the sky.

Here, Fig. 35, is the Earth plunged into that ocean of

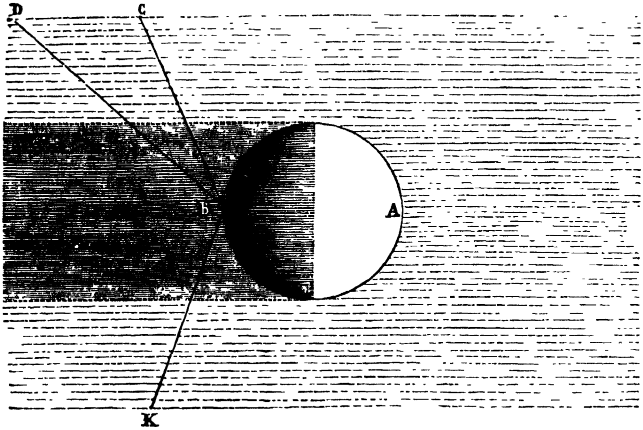


FIG. 35.

light. The hemisphere A, placed facing the Sun, has daylight, while the opposite hemisphere has night. An observer placed at B in the dark hemisphere may gaze into the sky along the lines BC, BD, BK, etc. In all these directions his sight will traverse luminous space where the Sun projects its full rays, yet that same space will appear to him to be perfectly dark. He only sees darkness in the midst of the splendours of the Sun. How is that? Let us remember what I have said before. Light is only visible to us when it falls straight into our eyes, or when it illuminates matter which sends it back

to us. If, therefore, there is no matter in celestial space, the light which travels through this space is to us as if it did not exist. In vain does it pass in torrents over our heads. Since it illuminates nothing on its way which could reflect it towards us, it traverses space without producing any impression on our sight, just as a ray of sunlight falling into a dark room is enfeebled when no more dust floats in its path, and would become quite invisible if there were no air.

8. Let us imagine, on the other hand, that some material substance extends round the Earth into infinite space. Then the lines of sight, BC, BD, BK, etc., would encounter a vista of particles which reflect the light to us, as do the grains of dust in the dark room ; and even in the absence of the Sun the sky would appear to us constantly illuminated, even in the middle of the night. A dark night would be impossible, and the sky would never be black. A dull daylight would succeed full sunlight, and that would be all. There would, indeed, be on the night side of the Earth a shadow where the Sun's rays would not penetrate ; but what would that shadow be ? It would be the shadow of a grain of sand, an insignificant shadow which hardly leaves a mark on the luminous immensity round it. But we do not experience that half day and night, for at a certain moment after sunset the sky becomes entirely black. We must, therefore, conclude that beyond the Earth and its atmosphere there is nothing material. And that is very fortunate, for if extra-terrestrial space were occupied by something material, by any substance however subtle, the conservation of movement would no longer be possible on account of the resistance that substance would offer, and a day would come when the Earth, gradually losing its mechan-

ical energies, would stop dead on its axis. The darkness of the night, therefore, demonstrates in the most conclusive manner that there is no material substance distributed in space round the Earth. It establishes particularly that the atmospheric layer enveloping the Globe does not extend farther into space. At some level the atmosphere terminates. That level may be high or low, but the atmosphere is limited as the watery ocean is limited.

9. Such as it is, the atmosphere nevertheless plays a great part in the illumination of the Earth. It substitutes a gradual transition for the sudden passing from day to night, which would take place in the absence of air. Long before mounting above the horizon, the Sun reaches with its rays the higher levels of atmosphere, which become illuminated and reflect down to us that brightness of the morning, the precursor of the day, which we call the dawn. And similarly the atmosphere remains for some time illuminated by the setting Sun, and there is upon the Earth that half-light which by insensible gradations merges into night, and which we call twilight.

Let us show in a diagram the terrestrial Globe enveloped by its atmosphere (Fig. 36). If the Sun is in the direction S, the last ray of light grazing the Earth will be BS, and an observer placed at N would receive no ray of sunlight and would thus in the absence of air find himself in total darkness. But as the rays of the Sun plunging into the volume of air of the region BC illuminate that region, the observer gets the benefit of the brightness reflected by that part of the sky. He has daylight, although the Sun is as yet invisible. As the day star rises and approaches the horizon NC the amount of atmosphere illuminated increases, and the illumination progresses from east to west in the sky over the observer.

Finally, the dawn comes to an end, and the real day commences when the Sun is found in the direction NC. In the evening the things happen similarly, but in the reverse order, after sunset. The light which no longer reaches the ground illuminates the heights of the atmosphere, and prolongs day until the moment when the Sun is definitely below the horizon, which may take more than an hour.

The duration of twilight is related to the thickness of the atmosphere. If that thickness were unlimited,

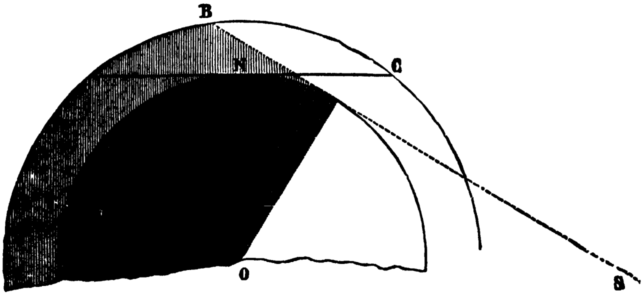


FIG. 36.

the evening twilight would meet the dawn. There would be no night, and even in the absence of the Sun the sky would always have a certain brightness. We may, therefore, deduce the approximate height of the atmosphere from the duration of the dawn. In that way, indeed, Geometry teaches us that at a height of 40 or 50 miles there is nothing material, there is no more air, since no reflection of sunrise traversing those high regions reaches our eyes. Beyond that distance, through the abyss of the void, there is open space where the mechanism of the heavens finds no resistance capable of disturbing its harmony.

NINTH LESSON

ATMOSPHERIC REFRACTION

Effect of the atmosphere on the temperature and brightness of the Sun, 1.—Influence of obliquity on the power of the Sun's rays, 2. —At the horizon, the Sun appears larger, 3.—The lamp in the mist, 3.—Estimation of distances, 4.—What deceives us as regards distance also deceives us as to size, 4.—The Sun visible before it is truly risen, 5.—The basin and the coin, 6.—Education of the eye, 7.—Objects are seen at the end of the beam of light, 7. —The broken stick, 7.—The density of the air increases from the limits of the atmosphere downwards, 8.—Atmospheric refraction, 9. —Illusory displacement of the stars, 9.—The Sun deformed at the horizon, 9.

1. We have learnt that the atmosphere distributes daylight to us uniformly by forming a luminous vault from which sunlight reaches us after being converted into thousands and thousands of reflections of diffused light ; by the action of dawn and twilight it extends the duration of illumination ; and it also brings about certain very remarkable appearances which we shall study in the present lesson.

In the first place, the rising Sun is less hot and less bright than it will be later in the day. When it appears on the edge of the horizon we can look into its face, but a short time afterwards no eye can suffer its blinding splendour. Yet the Sun emits, at any moment, the same heat and the same light ; its fierceness never declines and never increases. It is to the atmosphere that we owe these variations of luminosity. At noon, the Sun's

rays traverse the atmosphere vertically, through its smallest thickness, and since they do not encounter in their path any layers of air but those which have been freed from their vapour by the heat of the day, the rays arrive at their destination with only that loss of temperature and brightness which even the most transparent air inflicts upon them. But in the morning they traverse the air slantingly, and thus penetrate a greater thickness. They are enfeebled all the more because air next the soil is impregnated with the mists of the morning. A glance at Fig. 37 completes this proof. We see that in order to reach the point A on the Earth the rays from the rising Sun passing along the direction SA must cross a thickness of air CA. It is mixed with water vapour on account of its proximity to the soil, and is much thicker than the layer BA traversed by the Sun when it reaches the highest point of its course.

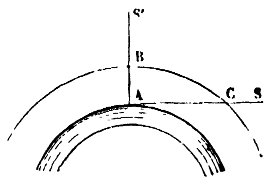


FIG. 37.

2. Another fact also intervenes. The rays of light, like the rays of heat, do not produce their full effect unless they fall vertically on the surface receiving them. If they come from one side their power is enfeebled by their obliquity. Hold a slate, a board, or a piece of cardboard near the light of a candle. If the light falls vertically on these objects they will be brightly illuminated, but if it falls slantingly they will be obscure.

Thus, independently of the atmosphere, the Sun's rays along S'A produce more effect in the way of heat and light than the rays passing along SA and just grazing the ground. As the Sun approaches the summit of the sky it acquires more power, since its rays fall more

obliquely and traverse a thinner and less misty layer of atmosphere. When it reaches the summit of the sky at noon, it possesses all its brightness; but in reaching that point it becomes feebler in its descent to the western horizon, and reproduces the same conditions as on the eastern horizon, but with less diminution of temperature and brightness, since the atmosphere after the hot day is more transparent than it is after the freshness of the night.

3. On the horizon, both east and west, the Sun has a peculiar appearance. Its disk seems to us larger than it is when high in the heavens, yet if we measure it in the morning, at noon, and in the evening with astronomical instruments we find its size to be always the same.[1] This is due to an illusion which is easy to explain. The Sun is so far away from us that it is impossible for the eye to gauge its distance and its volume. Is it large or small? Is it far away or close by? Our sight alone cannot teach us anything concerning these questions. Our eye is much too limited to grasp the spectacle of the Sun in its prodigious proportions. It only sees the luminous disk apparently fixed to the celestial vault. It judges this disk to be sometimes closer and sometimes farther away according to the brightness of its rays, and according to the perspective of the objects grouped in front of it.

Place a lighted lamp ten paces away in front of you. If the intervening air is transparent, the light will arrive in all its brightness, and the lamp will appear ten paces away; but if the air is misty and the brightness of the

[1] The same thing applies to the Moon, which appears to us larger on the horizon than high in the heavens. The explanation is the same as in the case of the Sun.

flame is dimmed or veiled by fog, the lamp will appear to be farther away. Who has not noticed that in the night the lights of habitations appear farther away in a mist than they are in reality ? Whence these erroneous estimations ? They are due to the fact that the mind, accustomed to judge the distances of objects according to clearness of vision, attributes the weakening of brightness produced by the imperfect transparency of air to an increase of distance.

4. An isolated mountain, seen alone on the horizon, deceives us as to its distance. We have the impression that we could reach it in a few hours, and yet whole days would not suffice. Why ? Because our gaze, directed towards that mountain, finds no preparatory perspective in front, no screen of hills, no line of landmarks which, stretching one behind the other, would enable it to estimate the distance by comparison. But if, on the other hand, the sight includes a row of mountains whose peaks are visible one behind the other, the farthest mountain is regarded as more distant.

Both these causes deceive us as regards the Sun. On the horizon the day star loses brightness on account of the misty veil near the soil. It also appears behind a long perspective of terrestrial objects placed between us and the edge of the sky. High in the heavens, on the other hand, it possesses all its brightness ; it reigns alone in the summit of the sky without any point of reference to aid the eye. In the first case it therefore seems farther away than in the second. But what deceives us as regards distance, also deceives us as regards size. An object which an illusion places at a greater distance, and which yet produces an image of the same size on the sensitive screen of the eye, also seems to us

larger, because we attribute the lack of diminution of the image in spite of an increased distance to an enlargement of the object. Thus, by the very fact that at the horizon it appears to us farther away, the Sun also appears to be larger.

5. The atmosphere is the cause of an even more remarkable illusion than the preceding one. The Sun is entirely visible before its real sunrise. It is also visible in its entirety after real sunset. At the moment in the morning when its disk is just completely visible, its upper rim is, in reality, just grazing the horizon. At the moment when in the evening it seems just to rest on the horizon, it has, in reality, descended below it. The atmosphere displaces the Sun from our sight; it lifts it, to some extent, at the horizon by an amount just equal to its width. The same applies to all the other celestial bodies. The air screen through which we see them make them appear higher than they are in reality. And that not only applies to the horizon, but to all the regions of the sky; only the deviation is less as the star is nearer the culminating point of its course. Only at the zenith is the star seen in its true position; everywhere else it occupies in appearance a place which it does not occupy in reality. Let us investigate the cause of this curious displacement.

Light is propagated in straight lines, but only on one condition: that it always passes through identical spaces, through the same substance, or, as we say, through the same medium. If it changes medium, it also changes direction, and it may do so quite suddenly. Let there be two different media (Fig. 38), separated by the plane surface MM': let there be air above, and, say, water below. Let a ray of light AB traverse the air and arrive

at B on the surface of the water. Instead of following its orginal direction, it suddenly bends and follows the direction BC, which makes with the perpendicular NN′ to the surface of separation an angle CBN′, which is smaller than the original angle ABN. A similar deviation happens if the ray passes from a vacuum into air, from water into glass, and in general from a less compact or less dense medium into a denser medium. We should always see the ray deviated at its entry into the denser medium, and approach the perpendicular. Hence we obtain the following law: *If a ray of light passes from a less dense medium to a denser medium, it is deflected from its first direction and approaches the perpendicular.*

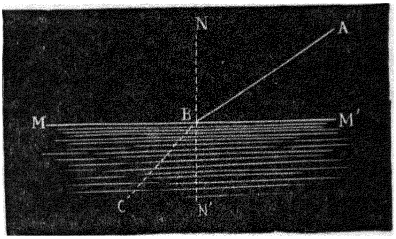


FIG. 38.

Let us now suppose that in Fig. 38 the ray of light passes from the water up into the air. In the water it follows the direction CB, but in penetrating into air it is suddenly deflected from its path and follows the direction BA away from the perpendicular. In passing from glass to water, or from air to a vacuum, or, in general, from a denser to a less dense medium, the ray of light would be deflected in a similar way. On penetrating into the less dense medium it would fall away from the perpendicular. Hence we have this second law: *If a ray of light passes from a denser medium to a less dense medium, it deviates from its original direction away from the perpendicular.*

6. The name "refraction of light" is given to this

change of direction undergone by rays of light when they fall obliquely from one medium into another. I say "obliquely" because there is no deviation when the ray is projected along the perpendicular to the surface separating the two media. Thus, a ray of light passing along the line NB would pass along BN′ without in any way modifying its first direction. But that is enough of this difficult subject. Let us now describe some experiments based on the play of refraction.

Place on the floor a vessel which is not transparent, such as a basin, and put a coin on the bottom of it. Take up a position so that your line of sight grazing the edge of the basin will just reach the coin. On moving slightly backwards, the coin will no longer be visible, being obscured by the rim of the basin. But if, now, another person fills the basin with water the coin by a strange magic becomes at once visible, although it has not changed its position and is really still masked by the edge of the basin. Magic is not the right word. Let us allow it to stand, since we have said it, but let us add that this is a very simple fact due to the deviation of the rays of light passing from water into air.

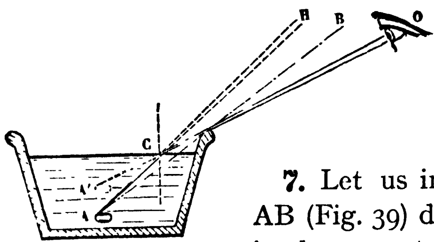


FIG. 39.

7. Let us imagine a straight line AB (Fig. 39) drawn from some place in the room to the rim of the vessel. That will be the direction of the last ray which can emerge from the basin before the introduction of the water, the other rays below AB being stopped by the opaque water. Then the coin is invisible to the eye placed at O. We put water into the vessel and the

condition is changed. A ray of light, such as AC, which without the water would continue its course in a straight line along CH, and would pass above the observer, is deviated from its direction on leaving the water and slants away from the perpendicular as soon as it comes from a denser medium into a less dense medium. It follows the direction CO and reaches the eye, which thereupon sees the coin, not where it is really, at A, but at the imaginary end of the ray produced, that is to say, at the imaginary point A′, whence the ray seems to come. "And why," you will say, "do we not see the coin at A in its real place in spite of the bend in the ray which makes it visible?" Because under ordinary conditions the object is always taken to be at the extremity of the beam of light received by the eye. Everyday experience has impressed upon our mind the conviction that a thing we see is at the end of a straight line of sight. The habit is ingrained, the education of our sense of sight is finished, and ever since then it does not matter if the luminous rays are bent on their way, once, 10 times, or 100 times, the eye takes no account of that; it sees the object at the imaginary point from which the rays appear to come in straight lines.

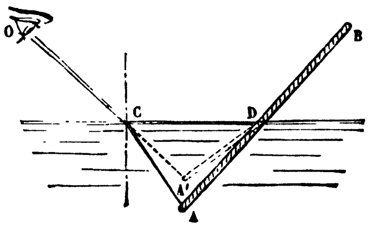


FIG. 40.

The same explanation applies to a stick half plunged into water, which appears broken at the point of immersion, and also shortened. The luminous beam AC (Fig. 40), coming from the extremity of the stick, is refracted on emerging from the water. It slants away from the perpendicular and takes the direction CO.

The eye, deceived by the refraction, sees the end of the stick at the end of the ray produced, that is to say, in A′. The other points of the portion AD indicate a similar imaginary displacement, and the stick appears to us bent at D and shortened.

8. The rays of light deflected from their path by their passage from water to air make visible to us the coin, which is really hidden behind the opaque rim of a vessel. Similarly, the rays of the Sun deflected from their path by the action of the atmosphere show us the Sun before

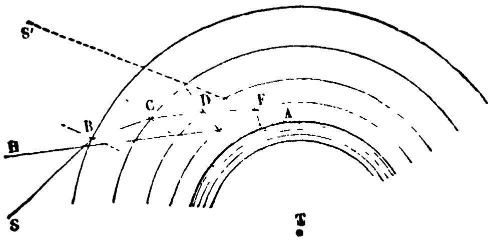


FIG 41.

it has risen, and after it has set. At the point A on the Earth (Fig. 41) let us produce the level ground of the soil indefinitely into space. This gives the horizon AH which separates the visible portion of the sky from the invisible portion. If there were no atmosphere the Sun will remain invisible from the point A so long as it is below that ideal plane. It would be hidden by the curvature of the Earth just as in our experiment the coin is hidden by the rim of the basin. It would only become visible on shining in the direction AH or above that line. With an atmosphere, the visibility commences earlier. You remember that the air is denser nearer the ground than it is higher up, being compressed by

the whole weight of the atmosphere of the higher regions. At sea-level it weighs one-seventh of an ounce per gallon, while at the upper level of the atmosphere its weight is almost zero. Therefore the density of the air is increased in an insensible gradation from the extreme top of the aerial envelope above to the region adjoining the ground. Let us represent this increase of density by concentric layers, the lighter ones outside, the heavier ones in contact with the Earth.

9. A ray of light arrives from the Sun situated above the horizon, and follows the direction SB (Fig. 41). In the absence of an atmosphere, that ray, if undergoing no deviation, would pass in a straight line above A without making the Sun visible. But it passes from a vacuum into a first layer of air, that is to say, it passes from a medium without any density at all, into a medium of a certain density. It therefore slants towards the perpendicular in the atmospheric layer,[1] and follows the direction BC. At that point it leaves one layer of light air in order to enter another of heavier air, which deviates it more and brings it closer to the perpendicular and sends it along CD. In D there is another deviation due to the greater density of the next layer, and at E the same thing happens. Thus by a series of inflections in the same direction, occasioned by the great density of the air, it reaches the observer along the direction EA. The eye has no knowledge of these changes of direction, and it sees the Sun along the ray of light which reaches it, that is to say, in the direction AES′. It is thus that, by the play of atmospheric refraction, the Sun is seen above the horizon at a moment when it

[1] A line is perpendicular to a circumference or to a sphere when it points straight at the centre.

is really below it, and becomes visible at a time when the convexity of the earth is really hiding it.

Another effect of atmospheric refraction is to deform the Sun's disk slightly at the horizon, and to give it the appearance of an oval pressed in the vertical direction. That is due to the fact that refraction is the stronger the closer the point considered is to the horizon. For this reason, the lower edge of the Sun is raised to a greater extent than the upper edge, and this unequal displacement gives the disk an oval appearance. This effect diminishes and soon ceases to be perceptible as the Sun rises. The same appearance is presented by the full Moon.

The illusory displacement produced by an atmospheric refraction affects every star at every hour of the day, but the more powerfully as the observation is made nearer the horizon. The star is not seen in its true position except at the moment when it passes the zenith, for at that moment it sends out rays perpendicular to the atmospheric layers ; and when light passes perpendicularly from one medium to another it experiences no deflection, as already remarked. In other researches, astronomers take care, of course, to correct the deceptive effects of atmospheric refraction, in order not to attribute a position in the sky to a star which is not its real position.

TENTH LESSON

INACCESSIBLE DISTANCES

An excursion to the Moon, 1.—Geometry again, 1.—The drawing of a head, 2.—Conditions of similarity, 2.—The inkpot and similar figures, 3.—To construct a similar geometrical figure we do not require the whole model, 3.—Use of this principle for measuring inaccessible distances, 4.—The tower across the river, 4.—Angular diameter, 5.—Measuring the real diameter of an unapproachable tower, 5.—Measuring the distance from the Earth to the Moon, 6 and 7.—Comparisons regarding that distance, 8.—Angular diameter and real diameter of the Moon, 8.—Circumference and volume, 8.

1. WHO has not followed the Moon with his eyes as it seems to rush along the sky behind the swiftly moving clouds ? [1] As the Moon approaches them the clouds appear a brilliant white, and look like a silver web. Then they become thicker and darker, and the Moon is finally hidden behind them. We see momentary glimpses of a vague globe behind the unequal curtain of the vapours. But suddenly there is a clear space, and the Moon appears in full serenity and looks curiously down upon us from the summit of the heavens. Then a thousand questions arise in our minds. What is that heavenly body in which we see the confused traces of a human face ? What is it doing up there in the cold spaces of the night ? Is it playing hide-and-seek with its

[1] It suffices to look at the Moon through the branches of trees in order to recognise that in a cloudy sky the clouds alone are in motion, and not the Moon.

neighbour the Earth among the clouds? What is its nature, and what is it made of? What should we find on it? Well, in order to satisfy your curiosity, let us make an excursion to the Moon with science as a guide. Are you ready? Then let us go. But no, halt. As careful travellers we must first ascertain the distance we have to traverse. One does not sally out on such an expedition without noting the length of the road. Let us measure the distance between the Earth and the Moon. But, you will say, that is impossible. Who will take a foot-rule and put it end to end along the line joining the Earth to the Moon? Or who will undertake to pace the road between us and the Moon, or stretch a surveyor's chain between them? It is Geometry which will accomplish the miracle. It is Geometry which, by a very simple combination of angles and straight lines, will tell us the size and distance of objects which we cannot approach. You, no doubt, wish to know something about those learned methods which measure the inaccessible; those beautiful and important methods which form one of the highest achievements of human intelligence. Let us put off our journey in order to consider them for a moment. You will thus see for yourself that it is possible to measure the distances from the Earth to a star instead of accepting the numbers given to you at my word. To learn and to remember are excellent things, but it is even better to understand and to see clearly.

2. You may have to copy a design or a head. Your copy may be as large as the model, or larger or smaller, but in any case it is essential to make the copy resemble the original. Nothing can be clearer. Here you have copied the nose, and it may have been your fancy to

make it in length and width just half the nose you have copied. I have no objection so long as you keep your work in due proportion. You pass on to the mouth. Since the nose has been reduced to half, is it not clear that the mouth must also be reduced to half its original size ? And the eyes, the ears, the chin, the forehead, the locks of hair, must not all these be reduced to half their former dimensions ? Just think of the singular effect which would be produced by a small nose placed beside an enlarged eye or tiny chin with an enormous mouth ! You would no longer have a smaller copy, but a frightful caricature. I need not insist, for you will understand that once the copy has been started with a nose reduced by half, it is essential for the resemblance that the eyes, mouth, chin, etc., should also be half their former size. If, on the other hand, you had begun with a nose enlarged to twice its size, the other parts of your sketch would also have to be twice the size of the corresponding parts of the model. This principle which nobody can deny for the copying of a head is equally applicable to the tracing of geometrical figures, and in every case we can say that *in similar figures the corresponding lines are in the same proportion.*

But this proportionality between various lines is not sufficient to produce a resemblance in the figures. There is something else. Supposing you had to trace a geometrical design similar to the model ABCDH (Fig. 42), with all its dimensions reduced to half. You would make *ab* half AB (Fig. 43), then you would make *bc* half BC ; then *cd* half CD ; and finally *dh* half DH. The equality of proportion between various corresponding lines is perfectly observed, and yet the copy does not resemble the model. What is wanting to make the resemblance ?

What is wanting is the equality of angles, which I have not considered in the demonstration. Let us resume the tracing, and take care to make the angles in the copy equal to the angles in the model. I shall make *a′b′* equal to half AB (Fig. 44); then at the point *b′* I shall construct an angle exactly equal to the corresponding angle of the model. And in continuing in that way I shall obtain the figure *a′b′c′d′h′* resembling the original design. Thus we shall say now: *In similar geometrical figures corresponding lines are in the same proportion and corresponding angles are equal.*

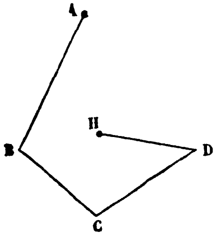


FIG. 42.

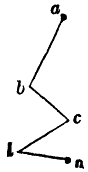


FIG. 43.

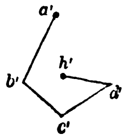


FIG. 44.

3. In order to design a head, a landscape, or anything else according to a model given to us, it is essential that that model should be visible throughout. If one portion is obscured by a great blot of ink, would you undertake to reproduce it truthfully as a whole? Certainly not. In order to copy a design you must first of all be able to see it. It is clear that that which is wanting, that which is unknown, cannot be imitated. Now, on account of their extreme simplicity, geometrical figures present a remarkable exception. They can be reproduced and copied with a rigorous similarity, although they may be unknown and partly invisible. We only require the following example as a proof. Supposing we have to

reproduce the polygon ABCDH (Fig. 45), reduced threefold. If the model were complete, as in Fig. 45, the task would have nothing peculiar about it. But supposing

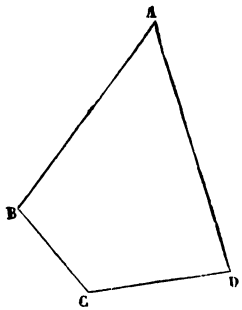


FIG. 45.

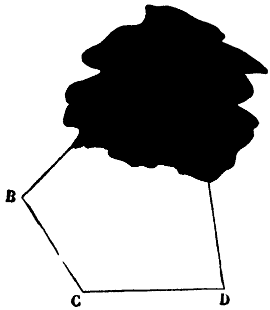


FIG. 46.

that it is spoilt by an ink-spot and put into the state in which we see it (Fig. 46), then the angle A is hidden from us as well as the length of the sides AB, AD. Can we yet, with the help of this incomplete model, make an exact reproduction of the original figure which we are supposed to be no longer able to see in its entirety? Let us try. I make the angle *c* (Fig. 47) equal to the corresponding angle C. On the sides of this angle I can have *cd* and *cb* equal to one-third of CD and CB respectively. Then at the point *b* I make an angle equal to the angle B, and that gives me the indefinite straight line *bx*. Similarly in *d*, I make an angle equal to D, and that gives me the indefinite straight line *dy*. These two lines, *bx* and *dy*, intersect somewhere, say at *a*, and the figure necessarily completes itself without my having to add anything to the construction, and without my paying any attention to the angle A or to the sides

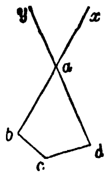


FIG. 47.

BA, DA, whose length is unknown to me. Since the copy completes itself of its own accord, and leaves no room for choice, it will reproduce the model rigorously, and there can be no other construction. Thus we may say : *In order to construct a geometrical figure similar to another, it is not necessary to know the latter in all its details ; it is sufficient to know so many that the construction after a certain point completes itself.*

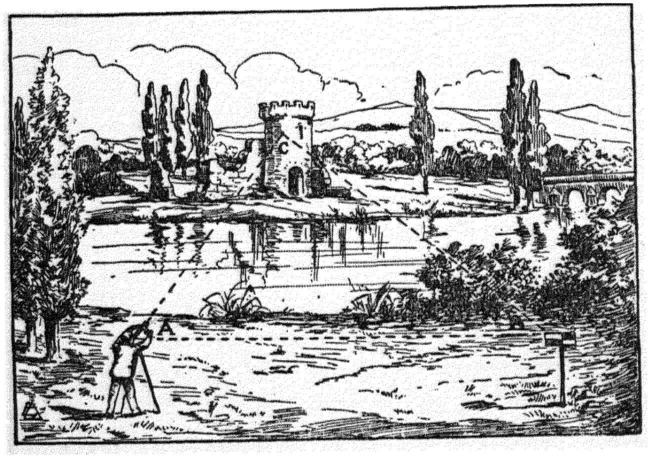


FIG. 48.

4. Let us apply this principle and its fruitful consequences to the following question. We are at A (Fig. 48), separated from the tower C by a river which we cannot cross, and we wish to know the distance AC which separates us from the tower as well as the width of the edifice. In order to do this, we plant on our bank at B, for instance, a surveying rod, and we measure with a yard-stick or a surveyor's chain the line AB, which we call our base. We may find it to be 70 yards, I suppose. Then with a theodolite placed at A we obtain the value

of the angle CAB. Let us suppose it is 52 degrees. Then the theodolite is transported to B in order to measure the angle CBA. Let that be 40 degrees.

After these measures, we shall know two out of the three angles of the triangle CAB, those at A and B, and we shall know one of the three sides, the side AB. All the rest, such as the angle C and the sides AC, BC, are unknown to us, not because they are hidden from us by a blot of ink, but because of something worse, the river obstacle which prevents us from traversing the distance to be measured. If in spite of the ink-blot we were able to construct a similar figure, the river obstacle will not hinder us from tracing on paper a faithful reproduction of the triangle ABC, half of which is unknown to us. Let us now draw a straight line *ab* (Fig. 49), 70 millimetres long, representing the 70 yards of the base AB measured on the ground. Let us construct at *a* an angle of 52 degrees, and at *b* an angle of 40 degrees. The two straight lines which intersect at *c* will necessarily complete the construction. Our tracing will therefore finish itself, and thus it exactly represents the original model on the ground. The two angles *abc* and ABC being similar, their corresponding sides will be in the same proportion. But *ab* is 70 mm. long, while AB is 70 yards. Thus *ac* will contain as many millimetres as the distance AC contains yards. We measure *ac* with a millimetre rule and find it to be 50 mm. long. Hence the distance we are seeking, AC, must be 50 yards. You see that in spite of the river which bars our passage the distance of the tower has been exactly measured.

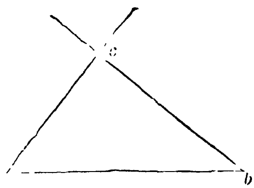


FIG. 49.

With the help of a similar figure constructed on paper, we require only a base and two angles for this interesting operation.[1]

5. Once we know the distance of the tower we can easily find its thickness or diameter. From the point A (Fig. 50), with the two telescopes of the theodolite the observer focuses upon the tower to the right and to the

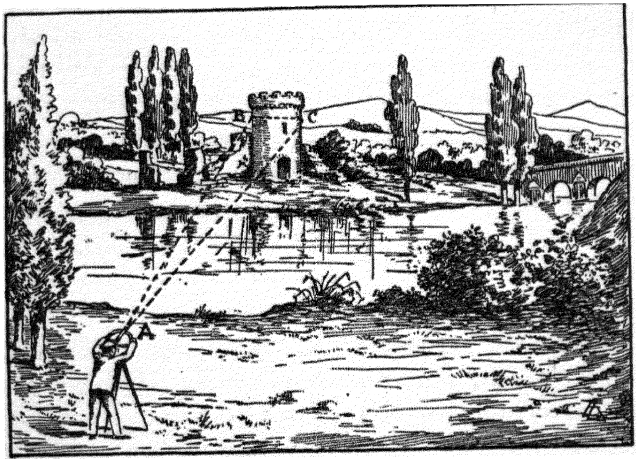


FIG. 50.

left so as to comprise the width of the edifice between the two sides of the angle produced. Let the angle BAC thus obtained be 10 degrees. That angle is called the angular diameter of the tower, since it comprises between its sides the real diameter, that is, the width

[1] Surveyors, instead of determining the unknown distance AC by constructing a similar triangle on paper, calculate it with the aid of the base AB and the two angles measured. The calculation of triangles is called "trigonometry." This method gives us a precision incomparably greater than tracing a similar figure. Unfortunately these calculations are too advanced for us.

of the tower. Now let us draw on paper an angle *a* of 10 degrees (Fig. 51), and on the sides reckoning from the apex let us cut off two lengths *ab*, *ac*, which equal 50 mm., in accordance with the distance of the tower which we know to be 50 yards. Having arrived at that point of construction, our figure will necessarily complete itself, for without any further research it suffices to join *b* to *c* to complete the triangle. The triangle *abc* thus constructed is therefore similar to the triangle ABC on the ground. Then the straight line *bc* represents, on a scale nearly 1,000 times smaller, the real diameter BC of the tower. Measured with a millimetre rod, *bc* turns out to be 9 mm. This means that the width of the tower itself is 9 yards.

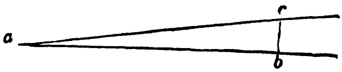


FIG. 51.

Thus, in order to obtain the size of an invisible object, we must, first of all, determine geometrically the distance which separates us from that object. Then we must measure the "angular diameter," or the angle between two lines of sight directed towards one point and the other on the extreme edges of the object. With this angle and the distance we have all that is necessary to solve the question. Let us admit that Geometry is extremely powerful. In the far distance, a thousand yards or a hundred thousand yards away or more, there is an object, a building, or a rock. Without our stirring from here, it tells us the dimensions and the distance as if it had measured them with the yard-stick. In researches made with its aid we need never say anything is impossible, because we should almost always be wrong.

6. If we had to judge the distance of the Earth from the Moon according to simple appearances, we should

commit the greatest errors; sight alone can teach us nothing about it. We see that the Moon is beyond the clouds, which themselves are 2 or 3 miles high, sometimes more and sometimes less, but how much farther is it away? That we cannot know without the aid of Geometry, so let us call that rigid science to our aid.

Two observers are stationed at two points of the Earth apart from each other so as to have a base corresponding to the distance to be measured. They take care to choose their stations on the same meridian. One of them may be stationed at Vienna in Austria, while the other is at the southern point of Africa, the Cape of Good Hope. Thus about one-quarter of the circumference of the Earth lies between them, a colossal base on which their geometrical scaffolding is to be erected. It is essential that the observations are made at the Cape and at Vienna at exactly the same hour, minute and second, so that the Moon can be seen by the two observers at the same point in the sky. How can they come to a precise understanding with regard to time at that distance? The Moon itself solves this difficulty, because a signal visible at the same instant to both observers is given by its disk. At certain epochs the full Moon becomes invisible, being eclipsed by penetrating into the shadow of the Earth, which masks its view of the Sun. Now the signal which the two observers await in order to commence their simultaneous observations is just such a lunar eclipse. At the precise moment when the shadow commences to reach the edge of the Moon they direct their telescopes towards that edge, and thus they take their measurements at the same instant at both ends of the Earth, as if the two astronomers were in communication.

7. These measurements reduce themselves to two angles as follows. Let VEC (Fig. 52) be the curvature of the Earth along the meridian passing both through Vienna, V, and through the Cape, C. Let E be the point where the equator cuts that meridian, and let L be the position of the Moon at the instant chosen by the observers. The astronomer at Vienna measures the angle HVL between the plumb-line and the line of sight directed towards the Moon with a theodolite; while the Cape observer measures the angle DCL between the vertical DC and the direction of the Moon, CL. That is all. They need only determine the latitude of their stations which, as we have seen, is the distance of these stations from the equator, and this they can determine by observing the celestial poles. These last measurements need not, of course, be done simultaneously, and each observer can take his time and determine the latitude of his station without regard to his colleague. Let the latitude of Vienna be 48 degrees, meaning that the arc of the meridian EV comprised between the equator and Vienna is 48 degrees. Let that of the Cape or the arc EC be 34 degrees. The sum of these two latitudes, which is the sum of the arcs VE, CE, represents the value of the angle COV contained between the two verticals, or between the two terrestrial radii of the stations chosen. The observation of the two poles therefore tells us that the angle COV equals 48 degrees added to 34 degrees, which

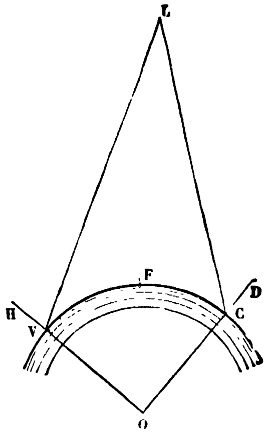


FIG. 52.

makes 82 degrees. That is all that is required for determining by means of a similar figure the distance between the Moon and the Earth.

8. In order to represent the curvature of the Earth, let us describe on paper the arc of a circle (Fig. 53), with any radius representing the radius of the Earth. Let us make an angle *cov* of 82 degrees. At the point *v* let us draw a line *vl*, making with the vertical *ov* the angle *hvl* equal to the angle which the Vienna astronomer obtained by the observation of the Moon. Similarly at the point *c* let us draw an angle *dcl* equal to that obtained by the Cape astronomer. The two straight lines, *vl*, *cl*, meet in *l*, and the figure *ovlc*, which finishes itself, is similar to the figure OVLC mentally traced through the interior of the Earth and the space of the sky. Now if we measure with the compass how many times the line *oc* is contained in *ol*, we find it is contained about 60 times.[1] The Moon is therefore distant from the Earth about 60 times the radius of the Earth. We say "about 60 times," for the distance is variable according to the position of the Moon. The greatest distance is 64 times the radius of the Earth, and the smallest is 56 times, the average being 60.[2]

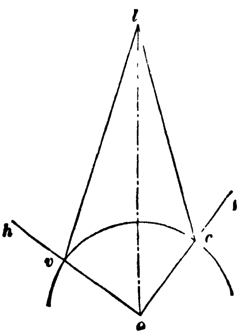
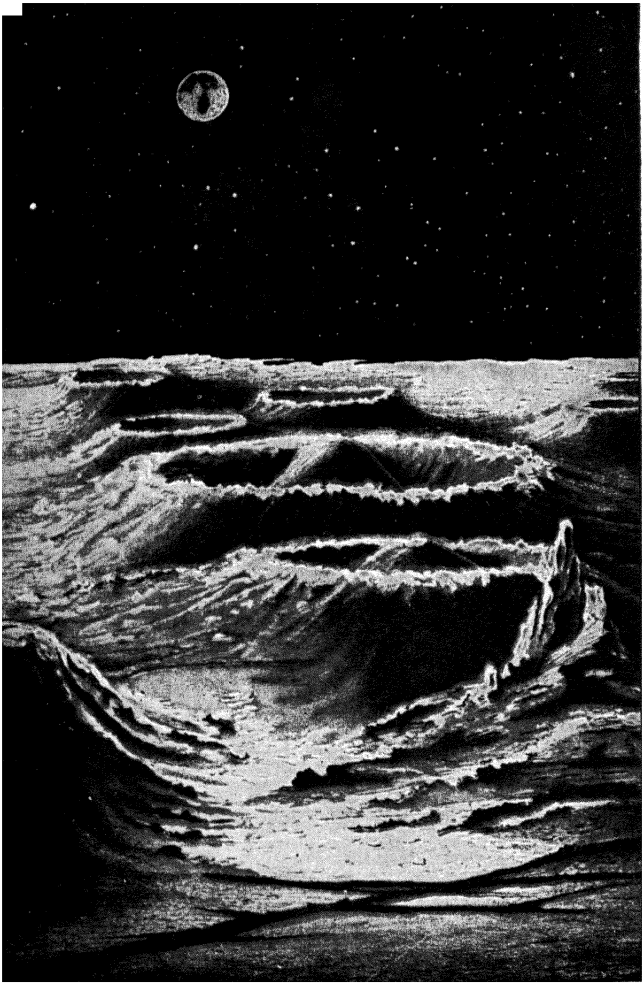


FIG. 53.

The appearance presented to us by the Moon seen amidst the clouds is therefore grossly deceptive. The

[1] We must not lose sight of the fact that the diagrams in the book are necessarily defective, since the dimensions of the page do not allow us to trace them in true proportions. In our diagram, *oc* is not contained sixty times in *ol*.

[2] Remember that the Earth's radius is in round numbers 4,000 miles.



D. LUNAR LANDSCAPE.

[To face p. 124.

Moon is immensely farther away than that. In order to reach it, we should have to put 30 globes like the Earth end to end, or we should have to stretch a string long enough to compass the Earth 9 or 10 times. A cannon-ball flying at a steady speed of 1,200 ft. per second, with which it left the cannon's mouth, would arrive at the Moon in 11 days. A train travelling at the rate of 37 miles per hour would only reach it in 9 months. Since it is so far away from the Earth, the Moon must be much bigger than it appears to be, for the distance must appear to our eyes much smaller than it really is. In order to obtain its real size we must repeat the operation we performed on the tower. We must measure its angular diameter and combine that angle with the distance. Now by focusing on the upper edge and the lower edge of the luminous disk we find that the angular diameter of the Moon is about half a degree. Let us then construct an angle of half a degree and cut off upon its sides 60 lengths representing 60 radii of the Earth. We shall thus find for the line which completes the triangle and represents the real diameter of the Moon, a value equal to about one-quarter of the earth's diameter, or, more precisely, three-elevenths. The Moon is therefore not a disk of a few spans, but an enormous globe, although smaller than the Earth. Its radius is three-elevenths of the Earth's radius. Hence its circumference is 6,700 miles, and its volume about one-fifth of the volume of the Earth. Now we can start on our projected excursion. If the way is long the wings of thought are swift.

ELEVENTH LESSON

AN EXCURSION TO THE MOON

Falling from a balloon, 1.—Traversing the atmosphere, 2.—Empty space, 3.—The limits of attraction, 4.—The travellers upside down, 5.—A 6,000-mile fall, 5.—Feebleness of gravitation on the Moon's surface, 6 and 7.—The bottom of a volcano, 8.—General aspect of lunar landscape, 8.—Shapes and dimensions of some lunar mountains, 9.—Crater of Heas in the Pyrenees and the lunar craters, 10.—Measuring the height of the mountains on the Moon, 11.—The crater of Tycho, 12.—Streaks and rills, 12.—A day on the Moon, 13.—Absence of atmosphere, 14.—Occultations of stars, 15.—Absence of water, 16.—So-called seas, 16.—Our organisation incompatible with physical conditions on the Moon, 16.—Extreme variations of temperature, 16.—What telescopes teach us, 17.—Lord Rosse's telescope, 18.—Eye of a giant 800 yards high, 18.

1. It must be a great moment for the balloonist when the last rope holding the balloon is let go. The aerial machine oscillates throughout its swollen bulk ; it is set in motion and starts on its journey. A stone sinks less swiftly into the abysses of the ocean than the balloon rises into the heights of the atmosphere. In a few seconds the crowd of onlookers is like an insignificant lot of ants ; houses look ridiculously small, and the town appears like a little heap of white cubes which could easily be held in the hollow of the hand. Here comes a cloud. The balloonist plunges into it and everything vanishes. Another rush, and the balloon emerges from the grey depths of the cloud like a marine monster coming to breathe on the surface of the water. It rises into the

higher levels, which are always serene and bathed in sunlight. It reaches a height of 6 miles, the greatest height to which mankind has ever penetrated. At intervals the balloonist sees the earth through holes in the clouds, but it appears vague on account of its distance, and terrifying by its depths. A dozen ropes and a wicker-basket hold him suspended over the abyss. What would happen to him if the frail craft were to be shipwrecked and thrown from a height of 6 miles? Our hair rises on end if we only think of such a fall. In three-quarters of a minute the unfortunate man would touch the ground at a speed of 140 feet per second, which is nearly the speed of a cannon-ball, and after the shock he would have lost his human form and would be unrecognisable. We divert our eyes from the horrible spectacle, and if you feel you have your courage sufficiently strong not to turn giddy we shall ascend together higher than the balloonist and proceed as far as the Moon. And for reasons of prudence and many other reasons we shall only perform the journey in our mind's eye.

2. On our way we shall find out certain facts concerning the atmosphere. Only the lower layers to the extent of 4 or 5 miles contain any clouds. Beyond that the air is too dry, being so free from vapour that no clouds would be able to form. In the upper regions of the atmosphere the weather is therefore perpetually fine. There are no storms and there is no lightning. The temperature falls very rapidly. Even at a few miles, the cold is very intense and the serene heights of the atmosphere have at all seasons a lower temperature than the most severe of our wintry days. The air becomes more and more rarefied, and soon ceases to be sufficient for respiration. The balloonists who have ventured to the greatest height,

Glaisher and Coxwell, who reached 6 miles, said that at the highest level they lost consciousness, blue with cold and suffocated by the lack of air. Between 5 and 6 miles above the ground life is so much endangered that it is doubtful whether man can ever reach yet higher levels. It is clear that we should have to renounce our voyage if we were undertaking it in any other way but mentally. We should hardly have left the ground before we were threatened with death by asphyxiation and cold. But as imaginary travellers we have nothing to fear, so let us proceed. What is this ? In the middle of the day the sky is getting dark. We left under a magnificent blue sky, and now that blue is turning more and more black. Night seems to be coming in the presence of the Sun. The reason for this celestial darkness is easy to see. We have only a small portion of air above us to produce diffused light. The luminous veil of the atmosphere is becoming thinner, and across this light veil we see the space where there is no more daylight because there is no more matter to be illuminated. Let us do this last stage with a rush and emerge above the atmosphere. Turn once more back to the Earth. With good eyesight you may see the surface of the aerial ocean swelling in enormous undulations and subsiding on the confines of our world. But we must pass on.

3. Now we have reached space and the infinite void, where the sun sheds its floods of light without producing daylight. When we look towards the Sun, blazing light threatens us with blindness, while in every other direction space is jet black, and stars shine in incomparable splendour. It is night in full daylight, and it is darkness amidst the light. Where there is nothing the Sun can illuminate nothing. In vain do its rays traverse the

desert immensity. The eye which does not receive them in a direct line regards them as invisible. We have entered the domain of eternal silence, the heavy silence of the void. No noise reaches us from the Earth, an explosion which would break up the Globe would not trouble our peace, for in the absence of all matter there can be no sound. It is also the domain of terrible cold which would kill the Earth, but for its atmospheric mantle. Where there is nothing to heat up, the heat of the Sun, like its light, remains ineffective. The most moderate computation places the temperature of these extra-terrestrial deserts at 200 degrees below freezing-point, which is three times the most intense cold of the exceptional winter of 1829. Certain delicate researches lead us to believe that the cold descends even to 270 degrees below zero. You will understand, I hope, that with such fatal conditions as are presented by the total absence of air at a very low temperature, life is altogether banished from inter-planetary space. But let us pursue our expedition across this terrible void. Why not? Imagination is a marvellous mount which laughs at danger, and takes you where you wish to go; it is apt, indeed, to go astray, and we shall have to be on our guard and control its assertions by the severe pronouncements of science.

4. We need not prolong our stay in this monotonous space. The Moon is our goal, and we will not lose any time. But a remarkable station is encountered on our way. On the imaginary line joining the Earth to the Moon there is a point which limits the respective domains of the two globes as regards attraction. Nothing distinguishes that point from any other point of space, and yet it is worthy of attention. Let me explain. The

Earth exerts her attraction on surrounding bodies and makes them fall towards her. The Moon also attracts them on her part. As the attraction is proportional to the mass, the Earth being larger and heavier is superior to the Moon when the distances are equal. But on the other hand the attraction diminishes with the square of the distance. Thus, if the body attracted is fairly near the Moon, the lesser distance would compensate for the feebleness of the Moon, and the smaller heavenly body may exert as great an attraction as the larger body, or even a greater attraction. Thus we have to determine the point where, on account of distance and mass, the lunar attraction balances the Earth's attraction, so that any body which happened to be placed there would be equally attracted by the Earth and by the Moon, and would fall neither towards the one nor towards the other. A calculation proves that such a point is found at nine-tenths of the whole distance of the two bodies, reckoned from the Earth, or at one-tenth as reckoned from the Moon. On this side of that limit the Earth rules supreme, while on the other side it is the Moon. Thus, an object situated on a straight line joining the two bodies would fall towards the Earth or towards the Moon according to its position on this side or the other side of the point of equal attraction.

5. We have reached that point, the frontier of the two attractions. Until now we have been travelling with the head pointing upwards to the Moon and our feet downwards towards the Earth, the mass which attracted us most. That position alone is the normal one, the only position proper to our conditions of existence, since a complete reversal, unless it were very short, would be fatal for us. Yet it is strange that at the point where

we have just arrived we must, in order not to suffer any inconvenience, turn our heads where our feet would be, and turn our feet where our heads should be. The reason for this is obvious. Once we have passed that limit we do not belong to the Earth, but we belong to the Moon, whose attraction is now superior. What we call " down " will now be towards the globe which attracts us, and that is the Moon. What we call " up " will be towards the attraction of the Earth, which we no longer obey. Henceforth the voyage will no longer be an ascent, but a fall. We do not rise, we descend. We fall towards the Moon from a height of 24,000 miles. We have no more effort to make to reach our goal, since the Moon's attraction carries us along with an increasing velocity which in a few minutes will become terrifying. A little time ago we shuddered at the idea of a balloonist falling from a height of 6 miles. What will it be when we fall from a height of 24,000 miles ? Well, all is over, and we have arrived, but it is just as well that we are only travelling mentally.

6. Where are we ? On a rocky slope resembling those bare escarpments which we find in some of the Swiss Alps. These are real stones we see, veritable rocks heaped in a terrible disorder. All of us have seen similar avalanches of boulders on the torn flanks of earthly mountains. The Moon, like the Earth, is a globe of stony material. But is stone heavy here ? Here we have a block which, according to its volume, should weigh 2 cwt. on the Earth, but we can lift it easily in our hands. A similar block of wood would be lifted on Earth with less ease. We might almost say it consisted of cork, so light is it. A singular country this, where stones weigh no more than cork weighs with us. But

everything participates in this lightness. A strange sensation warns us that, for us also, weight has been lessened. We have hardly any consciousness of our own weight, and our feet seem enveloped in cotton-wool, because we no longer feel the pressure of the ground. We hesitate in our walk because the effort of a step takes us farther than we wish to go; we walk without proper facility or proper equilibrium or proper weight. We are too light for the force used. There is no longer any harmony between the resistance to be overcome and the power brought into play, and this accounts for our pleasing awkwardness in trying to do the simplest thing in the world, viz. walking. Let us hope that habit will come to our rescue, and that we can ascend the slopes which surround us. But let me add one word meanwhile concerning the cause of this diminution of weight.

7. The weight of a body is not an inherent quality which it can take about, as it does its shape and its substance. Without adding anything to it, or taking anything from it, let us suppose that the same object is taken to double its present distance from the centre of the Earth, and we shall at once see that its weight, in other words its tendency to fall, becomes 4 times less. Weight results from the attraction exercised on the object. It increases inversely as the square of the distance. Since weight means a tendency towards the centre of attraction, the weight of a body is therefore subordinated to the attracting mass and to the distance of the centre of that mass. The Moon's mass is the 88th part of the Earth's mass.[1] Thus, at equal distances from the centres the weight of an object on the Moon

[1] This number has been deduced from the action of the Moon in producing the tides of our oceans.

would be 88 times less than its weight on the Earth. But since the radius of the Moon is only about one-quarter of that of the Earth, the reduction of distance partly supplements the feebleness of the mass, and when all allowances are made it results that on the Moon's surface bodies weigh 6 times less than they do on the surface of the Earth. Do you now see why each of our steps will be an involuntary jump? The muscles of our legs work as if they had to support the usual weight, whereas actually they have to support a burden 6 times less. It is just as if we gave a blow of the fist instead of a flip to a cork ball.

8. The place to which the chances of our fall have brought us is not very reassuring. The soil around us rises in sudden slopes of a bare and mournful appearance, and forms a conical chasm, a sort of large funnel, the bottom of which is lost in a chaos of darkness and rocky boulders. A mile above our heads the orifice of the crater opens with many gaps, like the rim of an immense well in ruins. We cannot doubt that we have fallen into the crater of a volcano. Such a situation would be dangerous on Earth, but here there is no danger. Astronomers, at least, have never found any eruption in lunar volcanoes, whose activity, it seems, has ceased for ever. Let us in any case get out of the volcanic funnel and look round at the landscape from the summit.

It would be difficult to find a stranger country. We might be on a gigantic cinder. An infinite number of volcanic cones succeed each other to the north and south, to the right and left as far as the eye can reach, larger and smaller, isolated or in groups grafted like warts one upon another. Some of them are like small molehills, and hardly rise above the plain. Others rival in their height

the highest peaks on earth, and their funnels are so deep that the Sun never reaches the bottom. Some are erected on an excrescence of the soil, while others are planted within monotonous enclosures which it would take several days to walk round. And on the flanks of these cones and at their base in the valleys which separate them we see the strangest collection of pinnacles, battlements, broken edges, and excrescences. It requires, no doubt, an enormous power to produce such convulsions of the soil.

9. What we see from the top of our observatory is repeated all over the Moon's surface. Everywhere the dominant aspect of the Moon is one of disorder, which reminds us in its enormous proportions of certain cantons of the Auvergne and of the Vivarais which are known to be covered with extinct volcanoes. With the exception of certain more or less level spaces which are miscalled seas, the surface of the Moon is variegated with mountains of volcanic shapes hollowed out in craters. The most usual form is that of protuberances hollow at the summit, giving a vast circular wall or circumference, the centre of which is frequently occupied by a dome or small cone. Are all these craters volcanic vents, as we see them on Earth? No. Their enormous dimensions preclude us from concluding that. The crater of Clavius [1] is 140 miles in diameter, and that of Ptolemy 114 miles, whereas Capernicus is 56 miles across, and Tycho 50 miles. How small are the craters of the terrestrial volcanoes like Vesuvius and Teneriffe in comparison, since they are only 600 feet and 460 feet across respectively. Their height is no less imposing. Ptolemy is

[1] The mountains of the Moon have been named after celebrated astronomers.

8,700 feet high, Capernicus 11,200 feet, Tycho 17,000 feet, Clavius 23,000 feet, Newton 24,000 feet, and Doerfel is even 25,000 feet high. If the small craters of the Moon can reasonably be compared to terrestrial volcanoes, the immense enclosures have a great resemblance to certain circular mountain ranges with crater-shaped valleys which in the Pyrenees are known under the name of *cirques*. These are not eruptive cones like Vesuvius or Etna, but regions where the surface of the Moon has risen under the pressure of internal forces within the planet, like bubbles which rise in the surface and whose centre collapses, leaving an amphitheatre of vertical walls.

10. And yet what a disproportion between the *cirques* of the Moon and those of the Earth. That of Heas in the Pyrenees is a gulf more than 6 miles round. Its walls are never less than 2,500 feet high. Numerous herds roam within these walls, the limits of which can hardly be seen. Three million people would not fill it up, while 10 million would find room on the gradients of its ramparts. Yet the majestic *cirque* of the Pyrenees is only a miserable object compared with those lunar *cirques* which are 250 or 400 miles in circumference, and whose walls reach heights of 3 or 4 miles. In the interior of the wall the amphitheatre has a greater depth because the interior of the lunar *cirques* is generally below the level of the external walls, as if the material of the Moon, fluid or softened at the distant epoch of these convulsions, had been driven back to the centre at the moment when the wall originated.

The volcanic character, so striking in the inequalities of the Moon's surface, is matched by another characteristic, which is equally remarkable, viz. their colossal dimensions

as compared with the Moon itself. Of the 1,095 mountains of the Moon whose heights have been measured, 6 are over 20,000 feet and 22 surpass the height of Mont Blanc, which is 14,000 feet high. The lunar peak Doerfel, with its 25,000 feet of height, is almost the rival of Mount Everest and Gaurisankar, the two highest mountains of the Earth, which are 29,000 feet high. If we consider the small volume of the Moon, the exaggerated size of the lunar mountains becomes even more striking. Gaurisankar represents in its height the 740th part of the Earth's radius, while Doerfel represents the 227th part of the Moon's radius. According to this comparison of the extreme heights, it is seen that the lunar mountains are three times higher in proportion than those of the Earth. A very probable cause of this excessive relief on the Moon is that gravitation is six times less there. If the mountains of the Moon are due, like those of the Earth, to central commotions and internal disturbances which have raised them above the general level, it is quite conceivable that the same force should produce more considerable effects where the weight of material lifted presents six times less resistance.

11. One thing will naturally astonish you. I have told you the size of the lunar craters and the elevation of the lunar peaks in feet. How do I know these numbers? How can we, from the Earth, measure the heights of the mountains of the Moon? It is not very difficult; unfortunately your geometrical knowledge is still too limited to answer the question for yourselves entirely, but I may tell you some of the principles on which that sort of calculation is made.

If we point even a small telescope at the Moon, its disk appears strewn with a prodigious number of round

or oval patches partly illuminated and partly obscure, and surrounded by walls or ramparts whose crests shine with great brilliancy. At the period of first quarter or last quarter, when the visible portion of the Moon is reduced to a crescent, the clearness of those hills is admirable, and we can recognise without any hesitation that the round bodies are cavities or enormous craters. The internal slope of the cavity which faces the Sun is brilliantly illuminated, while the opposite slope, which is shaded from the Sun's rays, is jet black. The peaks of the circular rampart seem to be flaming, and the whole mountain projects its own black shadow into the plains behind. Now it is the length of these shadows when compared with the Moon's diameter which guides us in ascertaining the height of the mountain and the depth of its crater.

We proceed as follows. If the Moon had a perfectly smooth surface, the line of separation between the part illuminated by the Sun and the dark part would be perfectly regular. But if we examine the Moon at first quarter we find beyond the line of continuous light a number of luminous irregularities, and particularly a number of isolated points which seem to be detached from the crescent. These points are the tops of mountains which, on account of their elevation, receive the sunlight before it reaches the surrounding plains, and which shine out while at their feet everything is still plunged into the darkness of night. From the distance of those bright points, reckoned from the line of continuous illumination, we can deduce the heights of the corresponding mountains, for the higher the peak rises the earlier will the Sun's rays reach it.

12. But we may go farther. Let us consider the

enormous indentations grouped in circles on our right. They belong to the crater of Tycho. You will notice that a rampart of vertical rocks is curved in a ring round it which our gaze can hardly take in. The diameter of this giant amphitheatre is 50 miles, and its circumference is 157 miles. The height of the walls is over 16,000 feet in places. If we wanted to fill up this chasm, we should require three of the greatest mountains on Earth: Chimborazo, Mont Blanc, and the Peak of Teneriffe, and even they would not suffice. The base of the amphitheatre is formed by a rough plain which shines like the internal walls of the ramparts with a peculiar brightness as if some crystalline matter had been thrown up from the interior of the satellite at the moment when the crater opened, and had left a vitreous coating where it flowed. And, finally, a cone 1,600 feet high forms a majestic pyramid at the very centre of the enclosure.

The external walls of the amphitheatre have less brightness, being apparently of a different nature. But outside it there are long bright streaks which start from the foot of the ramparts and radiate out across the grey ground, apparently consisting of the same substance as the centre and internal walls of the crater. From the Earth, they are seen as luminous bands, starting out from the crater, and numbering 100 or more. The craters called Kepler, Copernicus, and others, also form centres of similar rays. These brilliant bands never throw shadows, and therefore they are on the level of the ground. According to all appearances, the ground broke into star-shaped cracks round the centres of commotion about the time of the violent convulsions which gave rise to the craters on the Moon, much as a window-pane will crack round a point penetrated by a

stone. Then the internal matter, possibly vitreous, very reflecting and similar to the matter composing the internal walls and the bottom of the crater, came to fill up the crevices outside it.

Similar cracks, but rather different in aspect, are seen in different regions of the Moon. They are called "rills," and are crevices or straight tracks between two parallel dykes. Most of them are isolated, while several are joined like veins, or even crossed. Their length is from 10 to 120 miles, and their greatest width is 5,000 feet. In the full Moon they appear like white lines, since their cavity is entirely illuminated. In the crescent Moon they are black on account of the shadow projected into their cavities by the dyke not reached by the Sun. It is probable that these streaks are the latest of the numerous dislocations experienced by the soil of the Moon. They are certainly later than the formation of the amphitheatres, for some of them have penetrated some craters and broken across their walls.

13. After the disorder of the lunar surface, one fact strikes the observer very strongly. It is the strange sharpness of light and shadow, the brutal crudity of illumination. This sign alone takes us away from the things of this Earth, since our most familiar ideas on the distribution of daylight are contradicted. There is no more perspective throwing a misty veil over objects according to their distance. There is no gradation of tints, such as enables us to judge a distance on Earth. The horizon is not an undecided line bathed in a moving clearness, but a circle of crude definition where the last peaks visible shine with the same brilliance as the nearest ones. Beyond the range of sunlight there is not mere shade, but something much more intense and opaque.

It would be total blackness but for the many reflections of the rough ground. From the Earth, the smallest telescope shows us the Moon's shadows thus frankly black, and crudely outlined like an ink-blot on white paper. The Moon has no diffused light, it has no dawn or twilight. At the moment when the Sun rises or sets the day or the night comes suddenly without any transition, the former with its brilliant light, the latter with total blackness. The sky is never blue. Both in the daytime and at night in the presence of the Sun and in its absence the celestial void is equally black, and the stars shine in it continuously. We can hardly believe ourselves to be in the region of reality when looking at these luminous landscapes projecting the fantastic outlines of their craters half in darkness and half inundated with light under a sky in constant mourning and always strewn with stars. Are we, imaginary explorers, deceived by our imagination? No, because it is easy to make sure of the absence of an atmosphere on the Moon from the Earth, and then everything follows quite naturally: the lack of diffused light and twilight, the crudity of the shadows and the black sky filled with stars in the daylight.

14. A very simple observation shows us that even if there is an aerial envelope round the Moon it is not cloudy like our own atmosphere. If clouds floated in it we should see them roaming about the Moon's disk like patches changing in shape, but nothing of the kind is seen. If our sky is clear, the Moon is also perfectly clear. There is no wisp of cloud nor veil of vapour, which ever comes to spoil the clearness of our climate, on the lunar landscape.

But we cannot even admit an atmosphere of constant clearness. Of the facts which result from our own aerial

envelope, one of the most striking is the gradual transition between day and night. We pass from daytime into night and from night to day through twilight, which both morning and evening serves as a prelude to the change of scene, and is due to the light reflected from the upper air, the first and last to see the Sun. For an observer contemplating the Earth from a distance, the Globe would therefore not appear divided into dark regions and bright regions separated by sharp lines of demarcation. On the contrary, there would be between the region of shade and the region of light a zone of indecisive hue, the zone of twilight, giving a gradual passage from one to the other.

On the disk of the Moon nothing of this kind is seen. The dark portion and the bright portion are separated by a sharp line without intervening gradation. If there is no gradation of illumination between day and night on the Moon, the conclusion is obvious; there is no atmosphere.

15. We may arrive at the same result by the following consideration. You know already how the refraction of a ray of light by the Earth's atmosphere renders the Sun visible a little before it rises and a little after it sets You will also remember that a coin placed in the bottom of an opaque vessel and really hidden by the rim becomes visible by the fact of refraction when the vessel is filled with water. Now the Moon in its journey across the skies passes from time to time in front of some star; it hides the star, or "occults" it as it is called. If the Moon were surrounded by an aerial envelope, the duration of the occultation would be somewhat shortened, because the star, on account of the deviation of its rays by the lunar atmosphere, would be visible to us some little time

after it was really hidden by the disk of the moon, and a little before it ought to emerge from the opposite edge, just as on account of terrestrial refraction the Sun is visible for some moments before rising above the horizon, and for some moments after having set below it. Now, if we measure the duration of an occultation, it is found exactly equal to the time taken by the Moon to traverse its own width in the sky. In order that the star should remain hidden behind the Moon just for the time of such passage, it is necessary that the star's rays cease to reach us at the precise instant when the Moon's disk reaches the star, and that the star's light should reach us again at the precise moment when the disk, displaced to the extent of its width, no longer hides it. It is necessary, in other words, that the rays be not deviated from their rectilinear direction, nor refracted in grazing one or other of the rims of the Moon, and this logically implies the absence of an atmosphere. Let us guard ourselves against a too absolute negation. One point alone is certain; if the Moon possesses an aerial envelope, the substance of that envelope, which is not illuminated by twilight, and does not refract the light, is several thousand times more rare than the air of our own atmosphere. The vacuum produced by our air pumps is nearly as rich in its content of air, so we may give up these restrictions and assume zero.

16. The absence of an atmosphere necessarily implies the absence of water, for if there are any liquid layers—seas, lakes, or pools on the surface of the Moon—a spontaneous evaporation, made more abundant by a fortnight of continuous sunshine, would envelop our satellite with a great cloud of vapour. But clouds and vapours there are none, and the soil of the Moon is therefore dry throughout.

Yet astronomy employs the expressions *pond, lake,* and *sea* to designate certain portions of the lunar surface. We speak about the Sea of Nectar, the Sea of Crises, the Sea of Vapours, the Sea of Clouds and Tempests, the Sea of Serenity, the Lake of Dreams, the Pond of Sleep, etc., when referring to the grey patches, many of which can be seen with the naked eye. These are expressions consecrated by custom, but inappropriate. When we direct a telescope at these so-called seas, we find flat plains strewn with volcanic vents, crossed by cracks, and less bright than the mountainous districts.

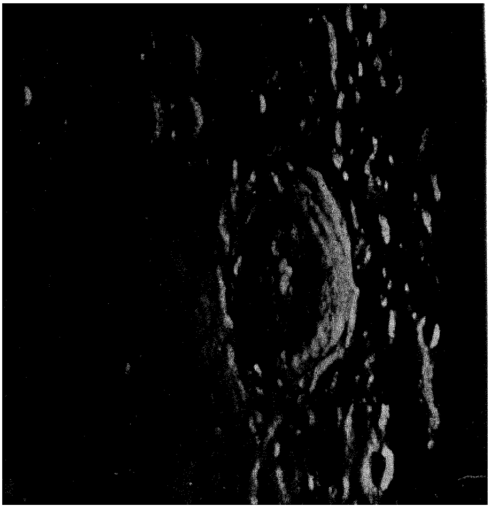
Neither water nor air! In the absence of these two essential conditions of life, the Moon is the exclusive domain of inert matter, the domain of the mineral, always supposing that organised life has immutable laws conforming to those of the Earth. It is a perpetual silent solitude, a desert of solemn immobility from which the plant and the animal as we know them are irrevocably excluded. A tuft of moss, in order to vegetate on the granite of our mountains, finds in the dew of night the drop of water necessary for its tender roots. It finds food for its leaves in the gas of the atmosphere, and that suffices for it. But on a rock of eternal dryness, which is deprived of the vivifying bath of the air, no plant can exist. Our tough lichens which are content with the bare rock, our mosses which can vegetate on the tiles of our roof, are therefore incompatible with the physical conditions of the Moon. Then what can we say of the higher plants, and particularly the animals, whose existence is much more delicate? Nothing corresponding to these can be found on the surface of our satellite.

We can assert this with greater reason, since in addition to the absence of air and water there is also a fatal

alternation of extreme temperatures. The Moon takes 30 times as long as the Earth to present its various sides to the rays of the Sun. For during 15 times 24 hours each of its hemispheres remains without interruption in the presence of the Sun. For 15 times 24 hours it remains plunged into the shadow of night.[1] If our summer days are exacting on account of their length, which is 16 hours at the most, what do you think of the lunar days of 360 hours, during which the continuous heat of the Sun is not tempered by any veil of clouds, nor the slightest breeze? Their temperature must be insupportable. A night of the same duration succeeds the day. The loss of heat is then excessively rapid, for there is no atmosphere nor gaseous envelope to protect the soil from freezing, and the temperature probably descends to the terrible cold of celestial space. Suddenly burnt by heat for 14 days, and then suddenly frozen with cold, what would happen to beings on the Earth if they were placed on the Moon? It is evident from every point of view that the Moon is a desert, unless organised life has resources which we cannot as yet suspect. But let us not speculate any longer, but leave the unknown its mysteries.

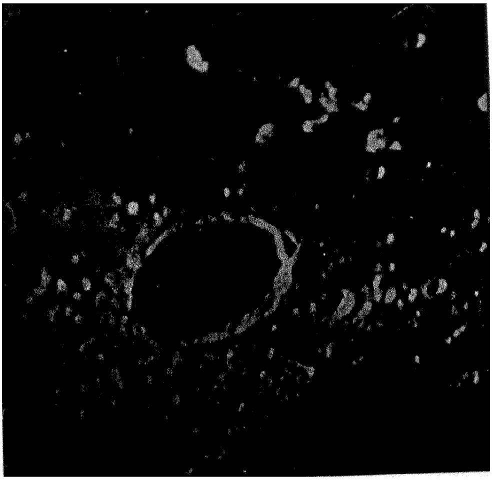
17. Cannot the telescopes which show us the curious details of the lunar soil solve the difficulty for us with their powerful vision and tell us whether the Moon is really absolutely barren? No. Astronomy does not yet possess apparatus sufficient to distinguish on the Moon such small objects as our own living beings on the Earth. The mean distance of the Moon is 24,000 miles. To reduce that distance 1,000 times, and to see the Moon as if we were at a distance of 240 miles, requires a telescope

[1] The duration of the lunar day on the average is 14 days 18 hours 22 minutes.



E. LANGRENUS.

10 September 1900.



F. LUNAR AMPHITHEATRE.

[*To face p.* 144.

which magnifies 1,000 times. To reduce that new distance to half, and see the Moon as if we were 120 miles away, we should require magnification of 2,000. From Lyons it is quite possible to see Mont Blanc, 100 miles away, with the naked eye, at least in its great mass. But it is unnecessary to add that at the same distance objects as small as a man, a tree, or even a house would be invisible. With a telescope magnifying 2,500 times, the mountains on the Moon would be seen as Mont Blanc is seen from Lyons. This would be marvellous for a considerable mass, and the great features of the soil, but it would be useless for seeing objects of small dimensions. But let us go further and say a magnification of 4,000 times, which would bring the Moon within 60 miles of the observer, or a magnification of 6,000 times, which would bring the Moon within 40 miles. Should we now see all the objects of the dimensions of our animals? Certainly not. Who would flatter himself that he could distinguish even a cow or an elephant at such a distance? You will, no doubt, tell me to increase the magnification still further until the Moon, brought as close as we like, will have no more secrets from us.

18. I agree; but I wish you to know that I have already considerably surpassed the limits of magnification which are found possible. Magnification has the inevitable effect of dispersing the light from the object over a greater space to the disadvantage of clearness of vision. When a certain limit proportional to the brightness of the source of light has been attained, the light is so thin and enfeebled that the object is no longer so clear. In the case of the Moon, the limit of possible magnification is reached soon on account of the feebleness of its light. We can hardly give you a magnification of 2,000, even

by employing colossal telescopes. Lord Rosse's telescope has a tube 50 feet long and 5½ feet in diameter. It weighs 66 cwt. A concave metallic mirror weighing 4 tons occupies the bottom of the tube. It gathers in a cylinder a great quantity of light which can, without becoming too feeble, undertake the dispersion necessitated by a great magnification, and yield a clear image of the heavenly body observed. The heavy instrument is upheld by enormous walls, veritable fortifications with battlements. A forest of beams and ropes sets it in motion and turns it towards the desired quarter of the heavens. As an instrument of vision, it is equivalent to an eye with a pupil 5 feet wide, the eye of a giant 2,650 feet high. Well, with this telescope the largest objects distinguished clearly on the Moon are comparable in volume to our cathedrals. Up to now it is, therefore, impossible to tell by magnification whether the Moon is really a dead solitude as is indicated by the closest analogies. The future will no doubt place telescopes of a greater power at the disposal of science, and sooner or later solve the problem.

TWELFTH LESSON

THE EARTH AS SEEN FROM THE MOON

The Earth reduced to a large Moon, 1.—France the size of a hand, 1.—The shining summits of the Alps, 2.—The craters of the Auvergne, 2.—The snows of the poles, 2.—The cloudy belts of the equator, 2.—Earth-light, 3.—The splendour of lunar nights, 3.—The ashen glow, 4.—Why the Earth shines, 4.—The Earth permanently invisible for one-half of the Moon, 5.—Experimental demonstration, 6.—The great clock of the Moon, 7.—The phases of the Earth, 7.

1. WHILE discussing the improbability of the existence of organised beings on the surface of the Moon, we have forgotten the crater of Tycho, whither our imaginary trip had transported us. Let us go back to that observatory to gaze from its summit upon the Earth, and let us choose a favourable time, the time when the Moon turns towards us its dark half, its hemisphere plunged into night. Where is our Earth now? Our prodigious Earth, the Earth which at one time seemed to be the basis of the Universe? There it is, indeed, in a corner of the heavens over our heads, a kind of large Moon which illuminates our landscape. Can it be the Earth, diminished by the distance? It is. There are Europe, Africa, and Asia clearly drawn as on the half of a map of the world, the seas are grey and slightly bluish, the continents are brighter, their light is white with a very slight shade of green, occasioned by the growths of vegetation. Objects of a uniform brilliance move about in

a diaphanous envelope which we can hardly perceive. They are accompanied by black blots on the luminous disk. They are clouds which float in the atmosphere and project their shadow on to the ground. On the horizon to the west, a little in front of the grey plains of the Atlantic, we see a corner of land which is dear to us all. It is our country, it is France, the head and heart of the nations. She thinks and feels, and the nations quiver with her ideas and aspirations. A great and irreparable void would be produced in the world if by some misfortune that corner of land should disappear, which, from the summit of our lunar crater, we can cover with our hand. There, on a finger's breadth of soil, live over 30 million of our fellow-countrymen. What are we in the sight of God who watches us from the depths of His glory, and from the confines of created things? Yet nothing escapes His Providence, who keeps the Earth moving on its axis for smaller beings than ourselves, who weighs the vast masses of the heavens, and yet gives to the insect its drop of honey, and to the blade of grass its drop of water.

2. To the south and east of the narrow region where we recognise France, some rows of points separated by deep shadows shine with exceptional brilliancy. These resplendent points are the snowy summits of the Pyrenees and the Alps, which vividly reflect the Sun's rays. The intervening shadows represent valleys where the Sun does not shine as yet. To the left of the Alps a clearer view would show a mass of conical cavities illuminated by the morning Sun on their eastern slopes and dark on their opposite sides, which are similar to those of the Moon, but for their dimensions. These are the volcanic funnels of the Vivarais and the Auvergne; but such small

craters could not be seen from the Moon without a telescope.

Let us now look upon the two ends of the terrestrial disk. At the southern extremity an immense space, irregularly broken by the sea, shines with a brilliance as great as the summits of the Alps. It is formed by a cap of snow and ice over the South Pole. At the northern end another brilliant region is seen, produced by the snows of the North Pole. It is smaller than the former, and for the following reason. It is just now summer for the northern hemisphere of the Earth, and winter for the southern hemisphere. Towards the north the snows, partly melted, have drawn back their limits towards the pole, while in the south they have gained on the frozen seas. In six months from now the opposite state of things will set in by the reversal of the seasons. The Arctic snows will gain in extent, and the Antarctic will recede.

Another remarkable peculiarity of the general aspect of the Earth is the following. In those nebulous objects of uniform whiteness, which roam over the terrestrial disk, we recognise clouds illuminated by the Sun. We see them to some extent everywhere, ranged without order, rare in some places, but abundant in others. But in the equatorial regions they have a peculiar arrangement, being disposed in irregular bands directed from the east to the west. This parallelism of cloudy belts is the result of the trade winds which blow the whole year round from east to west on account of the rotation of the Earth in the opposite direction.

3. We have just compared the Earth to a large Moon, and the comparison is a good one. From the point where we are the Globe appears like a great silvery disk. It is "full Earth" on the Moon, just as it will be "full

Moon" on the Earth, only brighter. The diameter of the Earth is to that of the Moon as 11 to 3, from which it follows that the terrestrial disk has a surface 14 times that of the lunar disk. Let us imagine 14 full Moons equal to that which illuminates our nights condensed into one and we shall have the effect of our Globe as it illuminates the lunar nights.

The full Earth is at this moment in its greatest splendour. The Earth, as large as a mill-wheel, sends down a torrent of white light from the heavens, and communicates an indescribable glory to the landscape. Sheets of molten silver seem to be pouring from the summits of the volcanic cones; the flanks of the craters seem to be painted with white light, the slopes of the hills stand out as if rubbed with phosphorus, and at our feet in the plains there is that which resembles a lake of luminous milk with dark patches for islands. This illumination, so soft and yet so powerfully vivid and cold, gives to the lunar nights a splendour of which we only get a glimpse on the Earth at certain epochs.

4. That is what happens at epochs when the Moon is seen in the shape of a thin crescent. Since the Moon only turns a small portion of its illuminated hemisphere towards us at those times, its whole disk should not be visible. Yet, if we watch the Moon with attention a little after sunset in autumn or spring, we see, besides, the crescent illuminated by the direct rays of the Sun, and the rest of the disk illuminated with an ashen-grey tint which is called "earth-light."

That brightness of the nocturnal lunar hemisphere is the result of the illumination produced by a full Earth, for at that moment our Globe turns towards the Moon its hemisphere bathed in sunlight. If the illumination of

the lunar nights is much enfeebled by the time it arrives on the Earth as earth-light, the numerous journeys of that light are the cause of it. The light has, in fact, travelled first from the Sun to the Earth; from our hemisphere it has been reflected towards the Moon as the light of a full Earth, and from the Moon it has come back to us reduced to a feeble glow by its many journeys and repeated reflections.

The Earth, playing the part of the Moon to the Moon itself, is, after all, only shining with borrowed light. Who has not noticed the dazzling light shed by a white wall, or even a road, when brightly illuminated by the summer Sun? The effect produced by a white, dusty road, or a wall covered with whitewash, is also produced in different degrees by any object struck by the Sun's rays. It reflects the light falling upon it, and thus becomes a more or less vivid source of illumination. The Earth, seen at a distance on its illuminated side, is therefore luminous on account of the brightness of the rocks, soil, clouds, waters, and, indeed, all those surfaces illuminated by the Sun. The Moon, in the same way, reflects the rays which fall upon its various rocks. The light of the full Moon and the full Earth is borrowed light, taken always from the Sun as a first source.

5. It makes no difference. Seen from the Moon, the Earth is a great and luminous object. Nothing in the lunar sky can be compared with it, not even the Sun. The latter, no doubt, being the original source of light, shines in sovereign splendour, but compared with the disk of the Earth it appears 14 times less in extent. Now this marvellous object in the lunar sky can only be seen from one-half of the Moon. To the other half it is unknown. This is due to the fact that the Moon always

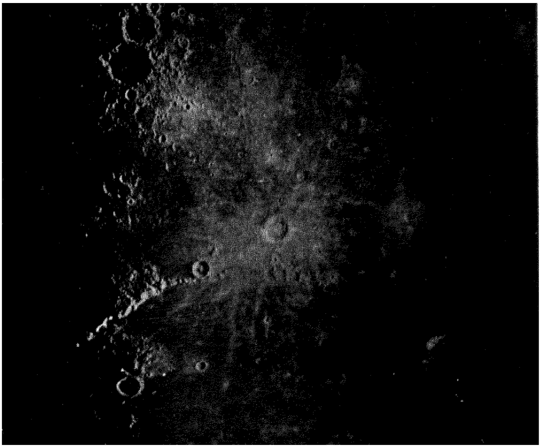
turns the same hemisphere towards us, as is shown by the permanence of the dark patches and luminous portions in which some people see the outlines of a human face. The face of the Moon, such as we see it now from the Earth, has been seen in exactly the same way from the earliest ages, and centuries to come will see it as we do. The other face will be for ever hidden from us. This does not mean that the Moon does not turn on its axis and successively expose all its sides to the Sun. It rotates on its axis as does the earth, but in a longer time, amounting to about 30 days. But in that same time it accomplishes its revolution round the Earth, so that, in accomplishing a portion of its own rotation, which ought to hide from us some regions and reveal others, it describes some portion of its orbit round us so as always to remain at the same point of view, and show us the same regions. Thus the Moon sees the Sun and the other heavenly bodies apparently revolving, rising, and setting in a fortnight, but the Earth remains invariably suspended at the same point in the heavens, exactly facing the hemisphere which we see.

6. This double rotation of the Moon on her axis and round the Earth, a rotation the opposite effects of which cancel themselves on account of their equal duration, can be imitated as follows. Stand in the middle of a room and make one turn on your heels. The various objects in the room, doors, windows, fireplace, etc., will pass in succession under your eyes, and the turn will be complete when the first object is under your eyes once more. Now place in the centre of the room a round table, and on that table a terrestrial globe, or any other object, such as an apple. That apple represents the Earth, and your head represents the Moon. Walk round

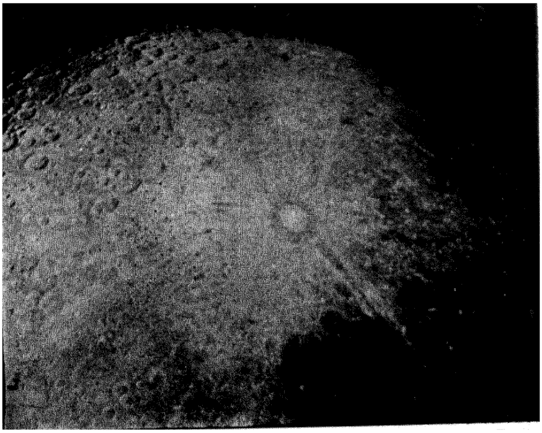
the apple, always looking towards it. The Moon, represented by your head, will therefore always turn towards the Earth, represented by the apple, the same hemisphere, in other words, your face; and when the turn round the table is finished, you will have made one rotation on your own axis, for the various objects in the room, doors, windows, fireplace, etc., will have passed under your eyes just as if, instead of walking round the table, you had turned once round on your heels. In looking at the apple you will have made one turn on your own axis, while you made one turn round the table. Similarly, the Moon accomplished one revolution round the Earth in the time of one rotation on its axis, and thus it always shows us the same hemisphere. From that hemisphere the Earth is visible, from the other it is never seen, any more than we, in the northern hemisphere, see the stars at the South Pole of the heavens.

7. While we speak of that half of the Moon which is deprived for ever of the magnificent sight of the Earth, the latter, high in the heavens, turns on its axis at the rate of 17 miles a minute at the equator. France, which occupied the western edge, has advanced towards the interior of the disk. Japan and Australia have disappeared; but the Atlantic is seen as a whole, and the eastern coast of America appears. In 12 hours, by the rotation of the Earth, France will have travelled from the extreme western border to the extreme eastern border, and the aspect of the disk will be entirely different. The continents and the seas formerly seen have been succeeded by the Pacific Ocean and the two Americas. The Earth will thus play the part of a majestic clock, indicating the hour by the constantly changing position of a sea, an island, or a country used as a point of reference.

Only in a few days the clock would no longer serve us; indeed, if we stayed here for a fortnight, which is the length of the lunar night, we should see the terrestrial disk dwindling gradually, and reducing itself to one-half, to one-third, and then to a thin crescent, which finally vanishes. The Earth, without the interposition of anything of a nature to interrupt the view, would become invisible for some time. For an observer, in fact, who looked at it from the Moon or from any other point in space, the earth is only visible on the side of its illuminated hemisphere; the other hemisphere cannot be seen on account of the very fact that it is deprived of light. Now, on account of the variable position of the Moon, the Earth turns towards it sometimes its illuminated half, and at other times its dark half, and then, again, part of one and part of the other at the same time. Hence the gradual change in the appearance of the Earth from the Moon, from a full, luminous disk to a thin crescent, a crescent as thin as a thread which finally becomes totally invisible. Nearly a month passes between two consecutive periods of full Earth. When the Moon turns its dark half towards us, the Earth turns its bright half towards it. It is the time of new Moon for us, and of full Earth for the Moon. Inversely, when the Moon is full for us, the Earth is invisible on the Moon. The following lesson will clear up this curious matter; but we must first get back to the Earth. It is time we did!



G. DIVERGENT RAYS OF COPERNICUS AND KEPLER.



H. THE AUREOLE OF TYCHO.

[To face p. 154.

THIRTEENTH LESSON

PHASES OF THE MOON

The reflections of a geometrician in the garden, 1.—Fall of a cannon-ball, 2.—The Moon falls like a bullet, 3.—Cause of the Moon's fall, 4.—Newton's demonstration, 4 and 5.—Celestial projectiles maintained in eternal orbits, 5.—Speed of the Moon, 6.—How the proper motion of the Moon is determined, 6.—Angular velocity and sidereal revolution, 6.—The phases, 7.—New Moon and full Earth, 7.—The crescent and ash-grey light, 8.—The first quarter, 8.—Full Moon and new Earth, 9.—The last quarter, 9.—Lunations, 10.—Synodic revolution, 11.—Proof of the revolution of the Earth round the Sun, 11.

1. NEWTON, the illustrious geometrician, who unveiled for us the mechanism of the Universe, was walking one day when still a young man in a garden planted with apple-trees. An apple fell to the ground. You would have picked it up and eaten it, and that would have been all. The geometrician in the garden asked himself why it had fallen. A clever question, you would have said; it fell because it was ripe, and because it detached itself from the branch. The young philosopher would have smiled at the readiness of your answer, but he would not have been satisfied by it; he was thinking of quite other things. If the apple-tree, he said to himself, increased its height by a miracle, and raised its fruit to a height of 2 miles, 10 miles, 100 miles, or 1,000 miles, would the apple still have fallen? Of course it would. At that distance from the Earth, the cause of the fall

might be feebler, but why should it vanish to nothing? And what should hinder the apple from falling? Nothing. And so the Moon, a large stony mass, must fall as the fruit of a tree would fall if its branches reached as high up as the Moon. The suspicion of the young philosopher concerning the fall of the Moon was well founded, and later he gave an admirable proof of the fall which I shall endeavour to explain to you. Yes, children, the Moon falls, and if it were ever to reach us it would be the end of us and of our poor terrestrial Globe, which would break in pieces under the overwhelming shock of the satellite coming down from the skies. The Moon is constantly falling, yet fortunately it always remains at the same distance from us. This must seem to you a strange paradox, but I shall hasten to give you the necessary explanations.

2. Let us imagine a cannon mounted on a hillock (Fig. 54), and pointing horizontally along the line CA; in front of the cannon, at a sufficient distance, there is a wall. The line of sight being CA, the shot, you might say, must hit the wall at the point A. But instead of describing the straight line CA, along which the cannon is aimed, the shot travels along a curved line CBD, and hits the wall well below the point aimed at, at D for instance. And in this case there is no awkwardness on the part of the gunner who aims the gun; you may suppose him to be endowed with every ability, but he will never hit the point towards which the gun is aimed, but always a point below it, so that if he really wants to hit the point A he must aim a little higher. Why does the shot not follow the line of sight of AB? And why does it hit the wall below the point aimed at? Nothing could be simpler; as soon as the shot leaves the gun it

ceases to be supported and it falls because, in spite of the movement imparted to it by the explosion, it is still subject to the attraction of the Earth. That is why its line of flight CBD descends more and more below the line of sight and forms a curve. And, furthermore, the gunshot falls to the same extent as if it were freely left to itself. Let us suppose, in fact, that in order to pass from the gun to the wall the shot takes one second of

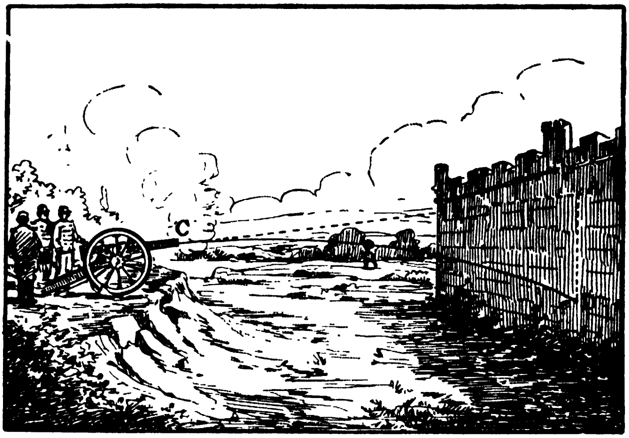


FIG. 54.

time. For one second of falling a body falling freely covers a vertical distance of 16 feet. Well, in measuring the distance from the point A, where the shot would have struck the wall if the Earth's attraction had not brought it lower, the point D is found, in reality, to be exactly 16 feet from A. If the gunshot had been flying for 2, 3, or 4 seconds from the gun to the wall, the length AD would have been 4 times, 9 times, or 16 times 16 feet, or still the exact height through which a body abandoned to itself would fall in the same time. Thus, while by

virtue of the impulse received the shot is sent forward in a horizontal direction, it is diverted in a vertical sense by reason of gravitation, and falls as if it were falling freely. In following the curved trajectory CBD it obeys two forces at the same time: the explosive force of the powder, which acting alone would make it traverse the straight line CA at a certain time from the gun to the wall, and the terrestrial attraction, which, acting alone, would make it fall in the same time through a height equal to AD.

3. The Moon in a little less than a month circulates round the Earth at the same time as it revolves once round its imaginary axis. In Fig. 55 the globe T represents the Earth, and the circular line round it represents the Moon's orbit; that is to say, the path which that body travels in its monthly voyage round us. When it arrives at any given point on its orbit, at L, for instance, the Moon has a certain impulse which urges it forward like a shot leaving the cannon's mouth. According to the principle of the inertia of matter, a principle by which every body, once started, will continue to move with constant speed along a straight line without end, it would therefore, if nothing occurred to alter it, go straight forward along the tangent LA, itself an indefinite prolongation of the small portion of the orbit it is traversing at that moment. In the same way as the gunshot, if the

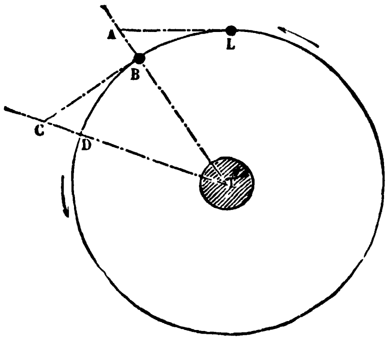


FIG. 55.

I. THE MOON AT FIRST QUARTER.

[To face p. 158.

attraction of the Earth did not make it descend when passing from the gun to the wall along the straight line CA (Fig. 54). Now it is not along the tangent LA that the Moon travels any more than the shot will travel along the line of sight. It travels along a curved line LB, and instead of reaching the indefinite vertical TA at a point A, which represents the same point in our cannon experiment, it reaches a lower point B; that is to say, it falls by the amount AB, just like the cannon-ball, which hits a point below the point aimed at. In the same way after arriving in B, the Moon, by virtue of its impulse and its inertia, would leave its orbit if it were unconstrained, and would go straight forward to hit in C the imaginary wall represented by the vertical CT; but in reality it follows the curve CD and arrives at D by a fall equal to the length CD. It is thus that, by an uninterrupted series of falls towards the Earth, the Moon instead of leaving our Globe for ever and going on an adventurous voyage through the immensities of space along the tangent or the straight line along which its impulse alone would take it, revolves round us as a faithful luminary in an orbit which is for ever renewed. I was therefore right in saying that the Moon falls, and it is precisely on account of its continuously falling that it remains at the same distance from us. If it did not fall it would rush along in a straight line and be for ever lost to us.

4. What is the cause of the perpetual fall of the Moon? Does the Moon, a colossal celestial projectile, obey the force of gravity like the gunshot? Is it drawn by the Earth's attraction like a common pebble thrown out of our hand? That is the problem on which Newton reflected under the apple-tree, as I have told you. The

demonstration which the great geometrician gave of this beautiful truth can find a place here.

A body falling towards the surface of the Earth covers a distance of 16 feet in the first second of its fall. If it is taken to 2, 3, or 4 times that distance, as reckoned from the surface of the Earth, it will be attracted with a force 4 times, 9 times, or 16 times less respectively, since the attraction diminishes in proportion to the square of the distance, and it would therefore fall in the first second of its fall through one quarter, one-ninth, or one-sixteenth respectively of 16 feet. At a distance of 60 times the radius of the Earth it would fall 16 feet divided by the square of 60, or $\frac{16}{60 \times 60}$ feet, which amounts to a little more than a millimetre, which is about $\frac{1}{25}$ inch. Knowing the distance fallen through the first second, it is easy to calculate how far the body would fall in one minute or 60 seconds, for we need only multiply the original amount by the square of the number of seconds.[1] In this way we can find for a fall of 60 seconds a height amounting to $\frac{16 \times 60 \times 60}{60 \times 60}$ feet, which is just 16 feet, that is to say, any body, a cannon-ball or a pebble, transported to 60 times the radius of the Earth, would fall back towards us and cover a distance in the first minute of its fall which is the same as the distance fallen through for the first second near the Earth's surface.

5. If the Moon falls according to the laws of terrestrial

[1] It is proved in mechanics that the space fallen through by a freely falling object equals the space fallen through in the first second multiplied by the square of the number of seconds during which it falls. The demonstration of this law would not be difficult, but it would take us too far from our subject.

bodies, then its descent towards the Earth must be 16 feet in one minute, since it is 60 times the radius of the Earth away. That is the prediction which we must confirm by experience. Let us look again at Fig. 55. Let us suppose that the Moon passes in one minute from L to B. The amount by which the Moon is lowered in comparison with its initial direction, below what we might call the line of sight, LA, in other words, its fall towards the Earth in one minute of time, is represented by AB. Now if we calculate by geometrical methods this line BA from the width of the circle described by the Moon, and the time taken by one revolution, we find from these well-known data that the distance fallen is just 16 feet. This is a wonderful result, which establishes the fact that the curvature of the Moon's path towards us, which keeps it always within the circle passing round the Earth, is produced by the Earth's attraction, which acts upon the Moon as it would upon any projectile in the sky. When, for the first time, this great truth dawned upon him, at which he had arrived by learned meditation, Newton was so much impressed that he had not the power of finishing his calculations. The illustrious thinker had penetrated the secret of the heavens, and had got a glimpse of Him whose thrice holy name he never pronounced without reverently uncovering his head. He had just come to understand how the heavenly bodies, once launched into space by the Creator, are mastered in their headlong flight and maintained in their perpetual orbits by their centres of attraction.

6. Animated by its original impulse, which is kept constant through all time and maintained by attraction in a circular orbit, like a mettlesome horse compelled by a halter to run in a circle, the Moon revolves round the

Earth in about 27¼ days, at a mean distance equal to 60 times the Earth's radius. Its speed is appalling. In one hour it covers 2,300 miles, though to us who observe it from the Earth the rush of our satellite is so much reduced by distance that it only reaches the eye of reason. Yet it is quite easy to recognise that the Moon is displaced in the sky by virtue of its own movement. Let us first get rid of the illusion occasioned by the rotation of the Earth upon its axis. The effect of this rotation is to show us the sky revolving round us from east to west in 24 hours, and carrying along with it the fixed stars in its vault, and the Moon and the Sun as well as the stars. We need not consider this general displacement, which is only a deceptive appearance, but only a special motion which we can make evident as follows. Let us observe one evening the Moon at the moment when it passes through its highest point in the heavens, and traverses our meridian. It passes our meridian in company with some star or another which we notice with care. Next day, at the same hour, the observation is repeated. The stars have come back faithfully to the meridian of the previous night; an interval of 24 hours has brought them back to the same point in the sky, or rather the Earth having accomplished one revolution has brought us face to face with the same landmarks in the heavens. But the Moon fails to keep her appointment, and is late to the extent of 13 degrees to the east of the meridian.[1] What is the cause of this lagging?

[1] More precisely, 13 degrees, 10 minutes, 34 seconds. This is what is called the daily angular velocity of the Moon, or the quantity by which it is displaced every day towards the east. A short time suffices to make this displacement of the Moon sensible. If we notice the position in the sky with respect to the neighbouring stars, we find that at the end of two hours or so it has got closer to the stars to the east.

Obviously it is that the Moon, animated by a proper motion, has changed its place in 24 hours in a direction opposite to the apparent movement of the sky. The following day there is another retardation, which is added to the first, and so on, until by the accumulation of such displacements the Moon has gone all round the sky from west to east, and is found again in the original meridian, in the company of the same stars. This occurs in 27 days, 7 hours, and 43 minutes, which is the length of what is called the sidereal revolution of the Moon. The Moon, therefore, turns round the Earth from west to east in an interval of 27 days and about a quarter.

7. Because of its movement of translation round the Earth, the Moon presents us at one time its illuminated hemisphere, and at another its dark hemisphere, and at other times a more or less great portion of one and the other at a time. These varying points of view give us those changes which we call the phases of the Moon. In Fig. 56, T is the Earth, while A, B, C, D are successively the positions of the Moon in its orbit. The Sun, whose rays are represented by parallel lines, is supposed to be on the right, at a very great distance. When it gets into the position A between the Earth and the Sun, the Moon is invisible, although it is facing us without any obstacle which could intercept our view. It is invisible simply because it turns in our direction the hemisphere not illuminated by the rays of the Sun, and therefore in darkness. The absence of light brings about this invisibility. Since the Moon is no more luminous by itself than is the Earth, we can only see that part of it which is brought into our line of sight and illuminated by the Sun. The remainder remains unperceived for lack of

illumination. Now you will see at once by the figure that at the point A of its orbit the Moon presents to us its dark hemisphere in full, and nothing but that. It is, then, quite natural that in that position it should be invisible. That is the time of the new Moon. The Moon, being situated on the same side as the Sun as seen from the Earth, rises with the latter, passes over the sky with it, and sets with it, always drowned in the

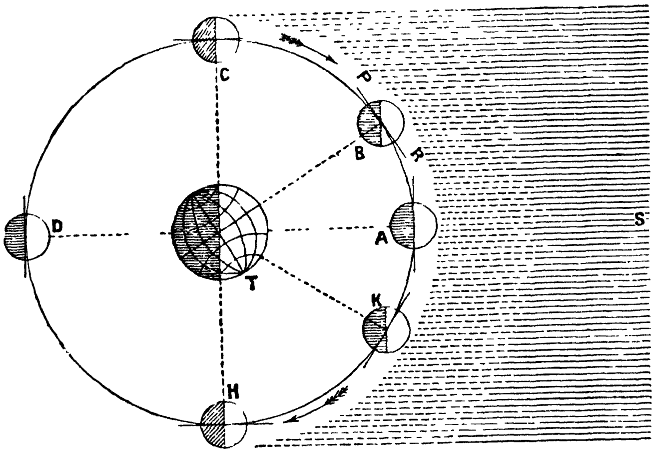


FIG. 56.

luminous beams of its radiant travelling companion. The immediate neighbourhood of the solar splendour prevents us seeing the ash-grey light or the earth-light which illuminates the nocturnal hemisphere of the new Moon. You will notice that in the position A, half of the Moon which is opposite the Sun faces the illuminated half of our Globe. It is therefore " full Earth " for the Moon at the moment when the Moon is invisible to us.

8. Three or four days pass, and the Moon, having passed from the point A to the point B of its orbit, is

seen in the west at sunset in the shape of a thin crescent, whose horns are directed towards the east, opposite to the point which the Sun occupies in its setting below the horizon. That crescent belongs to the illuminated hemisphere, which is beginning to turn towards us owing to the displacement of our satellite. In order to show the portion of the Moon visible to us, we must cut the Moon by a straight line PR perpendicular to the straight line joining the Earth to the Moon. All that is situated within this limit is within our view, and all that is beyond it is not. But in the half turned towards the Earth there is, as you see, a great portion of the dark hemisphere and a small white corner which is a small fraction of the illuminated hemisphere. That white corner corresponds in our plane figure to the luminous crescent of the lunar globe. At the time when the Moon appears in the form of a crescent the earth-light is seen merely on the dark portion of the disk, because the Sun, then past its time of setting, no longer hides it from our eyes by its bright illumination. It is at this time that the features of the lunar surface, craters, mountains, and amphitheatres are most clearly marked out by the contrasts of light and shade.

From one day to another the Moon sets later after the Sun, and from day to day its crescent is enlarged; at last, at the end of about a week, the satellite, having accomplished a quarter of its journey, reaches the position C. That is the epoch of the first quarter. The Moon then turns towards us, as seen in Fig. 56, half of its illuminated hemisphere and half its dark hemisphere, so that the Moon appears to us at this phase in the form of a luminous semi-circle. At the epoch of the first quarter the Moon culminates about 6 o'clock in the evening, and

sets about midnight, so that it only lights up the first half of the night. At this epoch, also, the earth-light ceases to be visible, because only half of the illuminated hemisphere of the Earth is seen from the Moon. Since the earth-light is reduced to half, the dark portions of the Moon have no longer sufficient illumination to reflect perceptible amounts of light to us.

9. In about two weeks the Moon arrives at D, which is opposite the Earth. Since the first quarter, its visible portion has gradually passed from a semi-circle to a complete circle, and now our satellite presents to us its entire illuminated hemisphere. On the other hand, the Earth now presents to the Moon its dark hemisphere. We have the epoch of full Moon, while for the Moon the Earth is invisible, or "new." The Moon then rises nearly at the moment at which the Sun sets. It sets when the Sun rises, and thus it lights up the whole night.

Towards the 21st day the Moon has traversed three-quarters of her orbit, and arrives at the point H. This phase is called the last quarter. The visible part of the Moon is reduced to a semi-circle just as it was in the opposite phase of the first quarter, but the times of rising and setting are reversed. The Moon then rises at midnight, passes over the meridian about 6 a.m., and sets when the Sun itself culminates. It therefore only lights the second half of the night.

After this last quarter, the half-moon begins to fade away. It is seen reduced to a crescent which rises in the east at the early dawn, and whose horns are directed towards the west opposite the rising Sun, which follows it more and more closely. The earth-light becomes visible again, because the obscure region of the disk begins to face the illuminated portion of the Earth's

disk. Then the crescent, thinner from day to day, disappears towards the 29th and 30th day. The Moon, coming back to the point A of its orbit, resumes the round of its phases. One lunation is finished and another commences, and so it goes on indefinitely.

10. The lunation, or the duration comprised between two consecutive passages of the Moon through the same phase, as, for instance, between two full Moons or two new Moons, takes, let us say, 30 days. Since the phases result from the translation of the Moon about the Earth, the complete period of the phases should, one would think, equal the duration of the revolution. But we have already seen that in order to complete its orbit the Moon requires 27¼ days, since in that time it completes its whole voyage round the Earth. Here would be a contradiction if the Earth did not change its place in the heavens, but were reduced to a mere rotation about its axis. But if the Earth itself travels round a dominating body like the Sun as the Moon travels round us, everything is explained. In the course of one lunation the Earth is transported elsewhere, and in order to catch it up and reach an identical position, the Moon must run after it for a certain time. Let us examine this more closely. Let us suppose that the Moon is full just now. It is high in the heavens in our meridian, just in the place of a certain star it has covered with its disk. To-morrow the Moon will pass the meridian later than the star, and after to-morrow still later, and so on day after day, until it has made a complete turn of the Earth in a direction opposite to the apparent rotation of the stars. Then the Moon is found at the same meridian in the company of the star to which we referred. We therefore find that the Moon has traversed its orbit when

it comes back to the same star. That happens every 27¼ days.

11. Now look at Fig. 57, where S is the point occupied by the Sun. T, the Earth, describes a circular orbit round the central Sun; and L, the Moon, turning round the Earth, accompanies it on its voyage. When the Earth is at T, and the Moon at L, the latter is full, since it is in a straight line drawn from the Sun to the Earth. At this moment the Moon seen from our globe corresponds to a certain star situated in the direction TE at an infinite distance. Twenty-seven and a quarter days pass by, and the Earth is transported along its orbit from T to T′. The Moon, finishing its circuit round the Earth, places itself in front of the same star in the heavens, which is now in the direction T′E′ parallel to TE. I say parallel, because the distance from the stars is so prodigious that the two lines of sight, TE, T′E′, both reach the same star, but can be considered as never meeting at all. Thus the Moon is at A when its sidereal revolution is finished; that is, when it corresponds to the same point in the heavens and has finished the round of its orbit. Does that mean that the lunation is achieved, and that for the second time the Moon is full? Obviously not, because in order to be full the Moon must still move from A to L′, opposite the Sun. Now, in order to go

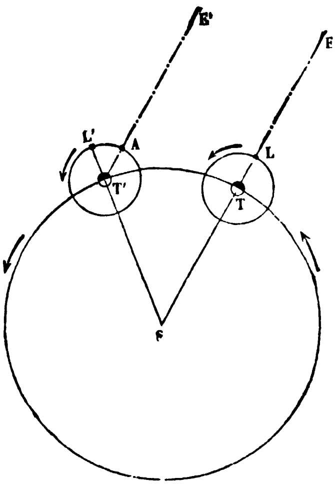
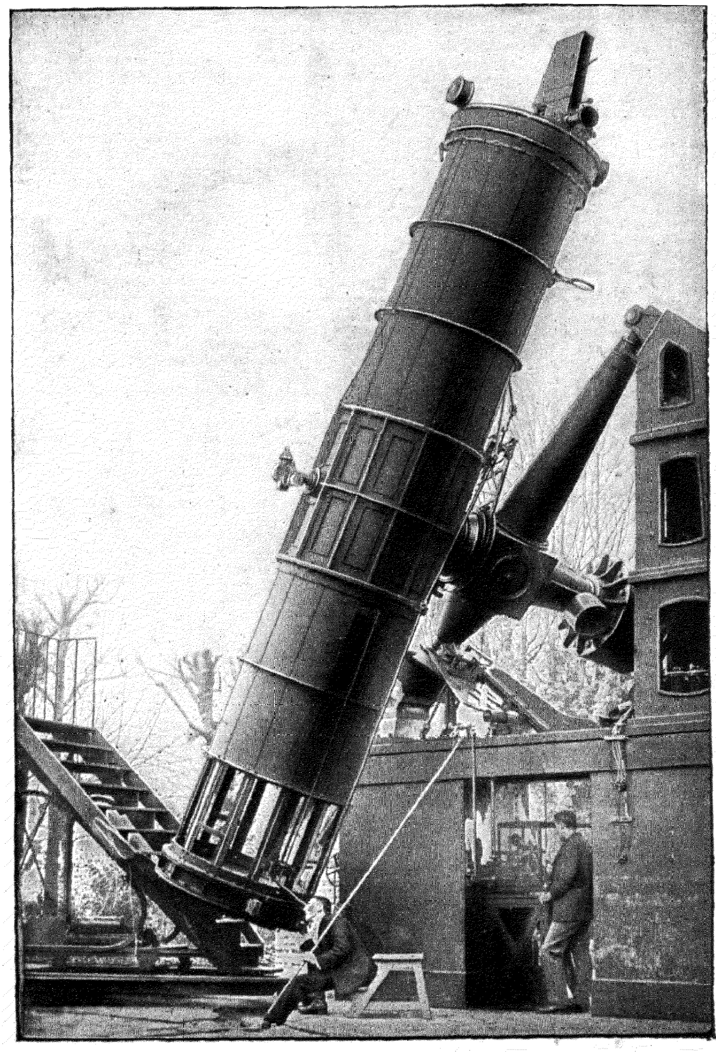


FIG. 57.



J. Paris Equatorial Telescope.

[To face p. 168.

from A to L′ and catch up the ground lost by the movement of the Earth, the Moon requires more than 2 days. The interval comprised between two consecutive full Moons is called a period of synodic revolution. The synodic revolution takes place in 29 days, 12 hours, 44 minutes, while the sidereal revolution takes 27 days, 7 hours, 43 minutes. We must always remember that the inequality of those two periods is a striking proof of the rotation of the Earth round the Sun.

FOURTEENTH LESSON

ECLIPSES

Light and shadow, 1.—The cone of the Earth's shadow. Penumbra, 2. —The conditions under which eclipses of the Sun and Moon are produced, 3.—Why they do not take place at every lunation, 3. —Partial and total eclipses of the Moon, 5.—Red coloration of the eclipsed Moon, 5.—Roundness of the Earth proved by the roundness of its shadow, 6.—Lunar eclipses general and simultaneous, 6.—Conditions necessary for eclipses of the Sun, 7. —A blackboard experiment on eclipses, 8.—Total, partial, and annular eclipses of the Sun, 9.—Continuous propagation of solar eclipses, 9.—Size of the shadow circle projected on the Earth by the Moon, 9.—Principal circumstances of a total eclipse of the Sun, 10.—Prediction of eclipses. The inviolable laws of the heavens, 11.—The Chaldean period, 11.—Relative frequency of lunar and solar eclipses, 12.—Total solar eclipses of last century, 12.

1. In the same medium light is propagated in a straight line. Thus, in entering a dark room through a slit in the blind a beam of sunlight traces a rectilinear band which is rendered visible by the illumination of the specks of dust suspended in the air. If we place an opaque body, such as the hand, for instance, in the path of this luminous band a dark shadow immediately appears behind it, since the beam, stopped in its path along a straight line, cannot proceed beyond the hand. This dark space is called a shadow. A shadow is therefore not a special obscurity cast by bodies ; it is the lack of light behind objects which stop the passage of a ray of light. It it were perfect and if no trace of light were to penetrate into it, the shadow of an opaque body would

be perfectly dark, and anything plunged into it would become invisible. The shadow of the hand in the beam of light is incomplete, because some of the light reflected by the air and the specks of dust not in the shadow penetrate into it. The shadows we see every day are incomplete also, since although the direct rays of the Sun do not penetrate into them there is nothing to hinder the diffused brightness of the atmosphere, the ground, and brightly illuminated objects from entering it freely. An absolutely black shadow cannot be produced in the daytime except in interplanetary space, where the absence of all matter makes diffused light, such as

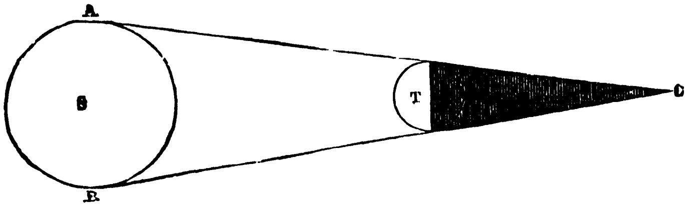


FIG. 58.

would throw its reflections into the region protected from sunlight, impossible. In order to form such a shadow, an opaque screen must be interposed in the path of the Sun's rays. What is such a screen ? There are several, and they are of colossal proportions : the Moon and the Earth, particularly, opaque globes which stop the light of the Sun as our hand stops the luminous band coming through the slit in the shutter, and which trail after them through space an enormous cone of shadow. Let us first consider the shadow of the Earth.

2. Let S be the Sun and T the Earth (Fig. 58). If we draw the two lines AC and BC, which touch the edges of both circles, and which are called in Geometry " exterior

tangents," we thus represent in a plain figure an imaginary horn or cone which would contain the Earth and the Sun, the Earth being in the bottom and the Sun at the mouth, like two unequal pellets in a horn of paper. It is clear that in the part of the cone situated beyond the Earth between T and C no ray from the Sun can penetrate, because in proceeding along a straight line it would have to pass right through the Earth. This region, TC, is called the cone of shadow, or *umbra*, and is the region where the Sun's light does not penetrate, being stopped

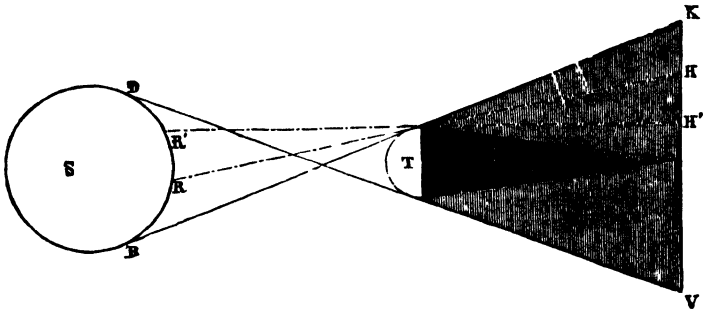


FIG. 59.

by the opaque screen of our Globe. This black cone has the circumference of the Earth itself for its base, which is 25,000 miles round, and its length is 216 radii of the Earth, or three or four times the distance from here to the Moon.[1] That is the size of the dark cone which travels through the heavens behind the Earth as our shadow travels behind us.

Now let us draw DV, BK (Fig. 59), which are called "interior tangents." They represent two imaginary cones joined at the apex, one of which envelops the Sun,

[1] Geometry deduces this length from the dimensions of the Earth and the Sun and the distance between the two globes.

while the other envelops the Earth. The space included by the cone KV and the cone of the umbra is called the penumbra. In this space darkness is not total as it is in the umbra, but the illumination is more or less feeble because the Sun is not seen as a whole from a point within it. Let us consider, in fact, a point in the penumbra such as H. If we draw a line HR touching the terrestrial Globe and reaching the Sun at R, we shall see by the figure that the portion of the solar globe situated below R can send no rays to the point H because the Earth is in the way, but that the portion above the line does send rays into the penumbra. At H, therefore, illumination is incomplete because the Sun is not entirely visible from the air. For a second point H′, nearer the full shadow, the illumination is still more defective, since the whole portion of the Sun below R′ is invisible. Thus, in the penumbra the brightness gets gradually feebler as the point approaches the umbra, since the amount of Sun seen is less. We must therefore consider three regions behind the Earth illuminated by the Sun: the region of full light, the umbra, and the penumbra. In the first, situated outside the imaginary conical envelope, corresponding to the interior tangents K and V, the Sun is visible without hindrance, and illumination is complete. In the second, contained in the cone corresponding to the exterior tangents, no ray from the Sun penetrates and darkness is total. In the third, which comprises the space between the two other regions, the Sun is only partly visible, and illumination decreases by degrees from full sunlight to total darkness. If some celestial screen were placed in space behind the Earth so as to cover the three regions at the same time, the umbra would form a circle of intense blackness, while the

penumbra would form a circle of graduated brightness round it and would in turn be surrounded by full sunlight.

3. No screen exists in the heavens which would permit us to see in its full extent the spectacle produced by the Earth's shadow, as we can see the shadow of a ruler projected on a sheet of paper. In vain does the dark cone extend for 8,700 miles into space, it can only encounter one body which is too small to serve as a complete screen. That body is our nearest neighbour, the Moon, which is distant from us by 60 terrestrial radii on the average, while the cone of darkness extends to 216 radii. That is more than sufficient to bring it about that the Moon is sometimes reached by the Earth's shadow, and even entirely submerged in it. What happens then? On entering the cone of the umbra, the Moon will cease to receive any light from the Sun, intercepted as it is by the Earth, and since it is not luminous by itself it will become dark and invisible; it will be "eclipsed." The eclipse of the Moon, therefore, implies one indispensable condition; it is that the Moon should be behind the Earth opposite the Sun. Let us go back to Fig. 56 in the last lesson, and we shall see that the condition is only fulfilled at the time of full Moon, or, as the astronomers say, at the time of opposition.[1] There should, therefore, be an eclipse every 28 or 29 days, the moment when the Moon, having reached the position opposite the Sun, becomes full Moon. But that is not the case, and the reason must now be stated. In explaining the phases you must have thought, no doubt (and

[1] We say that the moon is in opposition when it occupies the point D of its orbit opposite to the Sun. It is in conjunction when it is at the point A between the Earth and the Sun (Fig. 56).

I said nothing to correct you), that the new Moon is exactly between the Earth and the Sun, and the full Moon is in a straight line behind the Earth. But that is not in accordance with facts. In its voyage round us the Moon is rarely found in a straight line with the Earth and the Sun, since its orbit does not lie exactly in that direction. It sometimes passes above the line dividing those two globes, sometimes below it, not much, indeed, but enough to avoid projecting its shadow upon us, which would mean a solar eclipse, or entering the shadows of the Earth, which would be an eclipse of the Moon.

4. But while accompanying the Earth round the Sun, the Moon is constantly modifying its orbit, which is no longer circular, but becomes a very complicated, sinuous line, and this incessant modification occasionally places the three bodies in the same straight line. It is then, and only then, that an eclipse takes place: an eclipse of the Sun at the time of conjunction or new Moon, and an eclipse of the Moon at a time of opposition or full Moon.

When these two circumstances occur together—full Moon and the position of the three bodies in the same line—the Moon, being behind the Earth just opposite the Sun, cannot fail to enter our cone of shadow, which is three or four times longer than it need be to reach it, and wide enough to envelop it. Three cases can occur in the passage of the Moon behind the Earth: either the Moon plunges entirely into the full shadow, or it only partly enters it, or it simply traverses the penumbra. These three cases are represented in Fig. 60. When it is passing behind the Earth, near the direction (1), the Moon only traverses the penumbra, or that region of space where illumination is incomplete because the Sun, partly

hidden by our Globe, cannot put forth its full radiation. Then the brightness of the Moon diminishes a little, its great grey patches become deeper, and that is all; our satellite vanishes for a moment as if by the interposition of a light mist, emerges from the penumbra and regains its full brightness, without having been invisible for one moment. But that is not a true eclipse.

But let us suppose that the Moon follows the direction

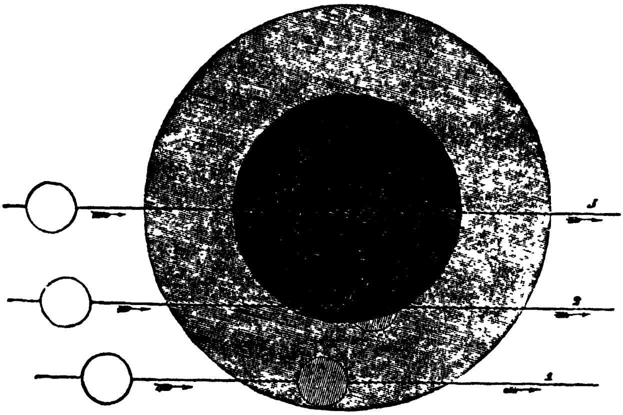


FIG. 60.

(2) (Fig. 60). It will first turn faint on entering the penumbra, then a black cap suddenly appears on the luminous disk, and invades it to a greater or lesser extent. That innovation is due to the partial immersion of the Moon in the umbra. Whatever plunges into the dark cone is entirely obscured, and becomes invisible because the Sun's light no longer reaches it. Whatever remains outside is visible, though somewhat tarnished by the penumbra. That is called a partial eclipse.

Finally, the eclipse is total if the Moon follows the direction right through the umbra, as it does in the

direction 3 of Fig. 60. Then, as it advances into the region of the umbra, the disk of the Moon is invaded by the shadow and then disappears when completely immersed in it. After a variable lapse of time it reappears on the opposite side. The duration of the total eclipse is, of course, more or less long according to the thickness of the umbra traversed by the Moon, the longest duration being when it travels through the centre of the umbra. In that case, the entire Moon remains obscured for about two hours. But taken in all its phases, from the time when the first break appears on the disk until it reappears, the eclipse can last some four hours.

5. The Moon does not always completely disappear in total eclipses; though it may be entirely plunged into the shadow of the Earth, it sometimes remains visible, but coloured a dull red. Such feeble visibility is occasioned by the atmosphere of our Globe. You know those glasses called burning glasses which collect the Sun's rays and assemble them into a very hot and bright point. They are called lenses. Their properties result from the deviation which they produce in light, or, in other words, refraction. Now the Earth's atmosphere behaves like a gigantic lens. It deviates the Sun's rays from their straight path, it refracts them and reassembles them behind in the space occupied by the Moon. The latter shows a faint glow in spite of the interposition of the Earth. In order to arrive at the Moon, the refracted rays must traverse the atmosphere through its greatest depth; also, in passing from the damp and dense layers near the ground, they are enfeebled and given a red tint, like the oblique rays of sunrise and sunset. This accounts for the copper colour of the eclipsed Moon. It is obvious, also, that the state of the atmosphere at the moment of

the eclipse must considerably modify the degree of visibility of our satellite. If the layers of air are sufficiently charged with vapours to extinguish the Sun's rays on their passage, the Moon may become entirely invisible.

6. If the Moon's disk were large enough to receive the entire shadow of the Earth, we should see that shadow in the shape of a black circle, and this would be a striking proof of the roundness of the Earth. The Moon is far from having the dimensions necessary to intercept the entire shadow of our Globe, yet at the moment of eclipse it furnishes us with another proof of the spherical shape of the Earth, since every time that it is partially eclipsed that portion of the shadow projected on the disk is a regular circular arc.

An eclipse of the Moon, partial or total, is not a local occurrence visible in some countries and invisible in others, or commencing early in one country and late in another. At every point on Earth the eclipse commences at the same time, and it finishes at the same time also. From one end of the Earth to the other, every country sees the eclipse in the same aspect, the only condition being that the Moon has not set. An entire hemisphere surveys the spectacle of the eclipse at the same time, and whatever point in space we occupied we should see the Moon being darkened as we see it from here. A lamp which is extinguished in a dark room ceases to be visible from every point in the room at the same instance. In the same way the Moon, which is extinguished on plunging into the Earth's shadow, and loses its brightness for lack of sunlight, is eclipsed at the same moment for every place on Earth. It is no longer visible, either from the Earth or from any point

in the heavens. Lunar eclipses are, therefore, general and simultaneous.

7. The eclipses of the Sun have the opposite character. They are visible at point after point, and only at certain stations. This you will soon understand. Let us investigate the cause. The Sun, the source of light, is not obscured like the Moon, by plunging into the shadow of another body. Darkness cannot exist in its presence, but an opaque screen may cut off our view of it, and then there is an eclipse of the Sun for us. The Moon is that screen. You will remember that it passes between the Earth and the Sun at the time of new Moon, when its dark hemisphere is turned towards us. If the three heavenly bodies were then in the same straight line a solar eclipse would take place, but I have already told you that that alignment is very rare on account of the inclination of the Moon's orbit. In general, the Moon passes outside a straight line joining the Earth to the Sun, and far enough away not to cast its shadow upon the Earth. Were it otherwise, there would be an eclipse of the Sun at every lunation. In order that an eclipse of the Sun should be produced, it is necessary that the Moon should be between the Earth and the Sun, that is to say, new Moon for us, and that it should be in line with the two other bodies. That point being established, make the following experiment.

8. Draw on the blackboard a rather large circle, and fill it with chalk. Then take in your hand a disk of cardboard or, better, a coin, and bring it closer and closer to one eye while the other eye is shut. Then take up a position facing the white circle. If the coin is near enough to your eye, it will hide the whole circle from you, however large the latter may be. It will, indeed, eclipse

it. But that sort of total eclipse only takes place immediately behind the coin. For persons situated to your right or to your left the round circle on the blackboard will be still visible. Now, without moving the coin from its place, incline your head a little so as to change the line of sight. You will immediately see the same circle reappear, but hollowed out like the crescent Moon. In these conditions the eclipse is partial. Bend your head still more. The crescent will grow and soon the whole circle will be visible, The eclipse will be over. Now go back to the first position so that the coin at your eye and the white circle are in the same straight line. At first the circle will be entirely hidden, but if you move the coin away from the eye exactly towards the circle, you will see that the latter will appear more and more round the edges of the coin, and form a ring round it. This sort of eclipse, which cuts off the view of the central portions and leaves the edges visible in the shape of a ring, is called an annular eclipse. In this case everything, of course, depends upon the position of the eye. Behind the coin, the eclipse of the circle is total at a certain distance ; a little farther away in the same line it is annular, on one side it is partial, and still farther away it is nothing. If there were several observers who were behind the same coin, each of them, according to his position, would see a different eclipse, and most of them would see no eclipse at all.

9. We may now substitute the Sun's disk for the white circle on the blackboard, and the Moon for the coin, and some region on the Earth for the eye of the observer, and then we shall have the exact theory of solar eclipses on the preceding argument. The Moon is too far away from us in comparison with its size to

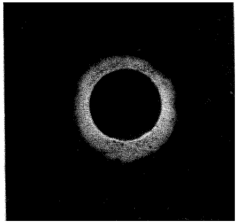
hide the Sun from all the Earth, or, in other words, to envelop our Globe in its cone of shadow.[1] We may compare it with the coin in our experiment, which hides the view of the white circle for an observer placed farther back, and only hides it partly, or not at all, for an observer standing a little on one side. In the most favourable circumstances, when the Moon is nearest, it may cast upon the Earth's surface a shadow in the shape of a circle 55 miles in diameter. For all points in the interior of that circle the Sun is entirely hidden and the eclipse is a total one. Nearer the circle the Sun is partly visible, and the eclipse is partial; still farther away the Sun is entirely visible, and there is no eclipse. Now, on account of the rotation of the Earth on its axis, and the translation of the Moon round us, this circle of shadow runs across the surface of continents and seas, tracing out a black band along the whole length of which the eclipse is total. On either side of this band the eclipse is partial, and the Sun appears hidden by the lunar disk, to a greater extent as the station is nearer the band of totality. Farther out there is no eclipse. You will now understand why the eclipses of the Sun cannot be general and simultaneous like the eclipses of the Moon. They are propagated from one point of the Earth to another, as the Moon advances and casts its shadow. In our former experiment we may suppose the spectators ranged in front of the white circle on the blackboard. Then, suppose the coin moves along and intercepts their sight one by one. The circle

[1] The length of that cone varies from 57 to 59 radii of the Earth. The distance of the Moon from the nearest surface of the Earth varies from 56 to 63 radii. We can see, therefore, that according to circumstances the shadow cone of the Moon may not reach the Earth at all, or may only reach it with its extreme point. In the latter case, the black circle produced on Earth by the shadow of the Moon is 55 miles wide at the most.

will become invisible for everyone at some time, but its invisibility will move along from one person to the next. At the same moment, according to the position of the coin, the eclipse of the circle will be total for one spectator, partial for another, and nothing for yet another, and so it is with the eclipse of the Sun.

If the Moon is sufficiently removed from us it can no longer obscure the Sun entirely, just as the coin allows us to see the circle to some extent when we move it farther away from the eye. In such cases the Sun projects beyond the black disk of the Moon and is for a few moments in the form of a narrow luminous ring. Hence the eclipse is called an annular one. The eclipse thus annular for certain parts of the Globe may at the same time be partial or nothing for others, even at the same instant.

10. A total eclipse of the Sun is one of the most solemn experiences which are ever given to us. We notice that, without any apparent cause, and in a sky flooded with light, the western border of the Sun shows a black indentation. It is the invisible disk of the Moon which, seen from our point of view, is about to project itself upon the solar disk. The black screen advances and the black spot increases. Soon the Sun, half extinguished, seems struggling to illuminate the sad-looking landscape with its livid rays. From minute to minute it becomes thinner, until the extreme edge of the expiring day star disappears, and it becomes dark, suddenly but not completely, because round the black circle of the Moon there is an aura of pale light as yet unexplained, and called the "corona," which sometimes produces magical effects. Then in the dark firmament the stars, formerly effaced by the brightness of the atmosphere, become



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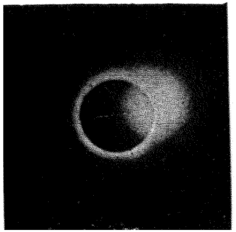

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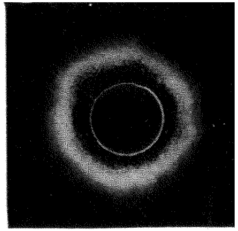

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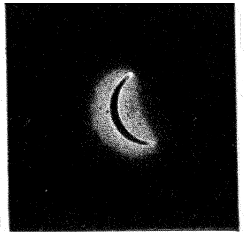

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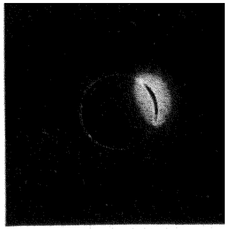


(3)

K. SOLAR ECLIPSE OF 30 AUGUST 1905.

[To face p. 182.

visible, or at least the brightest of them. The temperature falls, and so does the dew, and there is a sudden feeling of cold. Plants fold their leaves and close their petals as if for the night. Those sad friends of twilight, the bats, leave their retreats to flit about the air; birds, on the other hand, put their heads under their wings, or seek their nests with uncertain flight. Draft animals lie down in the road with little regard to the whip which drives them on. The cattle range themselves in circles in the fields with horns pointing outwards as if to meet a common danger. Chicks take refuge under their mother's wings, dogs tremble with fright at the heels of their masters, and man himself, though he knows the cause of the unusual darkness, and calculates its coming in advance, cannot escape a vague disquiet. In face of this sombre phenomenon, everyone feels some involuntary apprehensions within his soul. A few minutes, five at the most, pass by in this anxious suspense, then a flood of light flashes out, the radiant day star emerges more and more from the black screen of the Moon and the illumination of the daytime comes back by degrees.

11. In times of ignorance, eclipses threw terror into all nations. They were looked upon as terrible precursors of the wrath of Heaven. To-day, trained by science to saner ideas, we see in eclipses the expression of eternal laws which move Moon and Earth in immutable orbits, and bring them back after fixed intervals into line with the Sun. They no longer mean to us a warning of a plague, but a definite proof of the order perpetually imposed upon the Universe by the Divine Architect. The astronomer, familiar with the mechanics of the heavens, not only calculates an eclipse as long beforehand as he wishes, but he predicts the day and hour, and the

precise moment of its arrival. He says in what places it will be total, and in what places it will be partial, and never do the facts belie him, for he relies upon the invariable data of the immutable laws of Nature, the precious heritage of science. It is not possible for us to follow him in his arduous calculations. We need only know that after 18 years and 11 days the eclipses return in the same order, both those of the Moon and those of the Sun, and this period is called the Chaldean period. It suffices, therefore, to note all the eclipses of a period of 18 years and 11 days to be able to predict eclipses for the following periods. That is, indeed, but an approximate method giving an approximate date without specifying the aspect of the eclipse or the moment of appearance and the limits of visibility, but for more circumstantial details the resources of the highest Geometry must be called in aid.

12. In this period of 18 years 11 days there are always 70 eclipses, 41 of the Sun and 29 of the Moon; but for a given place the eclipses of the Sun are nearly three times more rare than those of the Moon. This is due to the fact that the eclipses of the Moon are general and visible simultaneously by the whole hemisphere facing the Moon, whereas the eclipse of the Sun only corresponds each to a limited portion of the Earth's surface. In any one year and for the entire Earth there are seven eclipses of the Moon and the Sun at the most. There are two of them at least, and four on the average. For any given place there is only one total eclipse of the Sun every 200 years. In considering, not the precise place, but the entire surface of the Globe, the total eclipses of the Sun are not very rare. In the nineteenth century there were 12. That of 8th of July, 1842, was visible

in the south of France; that of 20th of July, 1851, in the north of Germany; that of 15th of March, 1858, in England; that of 28th of July, 1860, in the north of Spain; that of 25th of April, 1865, in South America and South Africa, and so on.

Who knows but that one of us, exiled by the exigencies of our busy life, may be present one day at one of these total eclipses, whose date science reads in the book of the future?

FIFTEENTH LESSON

THE SUN

Terrestrial bases insufficient for measuring the distance of the Sun, 1. —Method of Aristarchus of Samos, 2.—Method of the transit of Venus, 3.—The Sun's distance. A voyage of three centuries and a half, 4.—The Sun's volume. The grain of wheat and the 140 quarts, 4.—How the Sun is weighed, 5.—The fall of the Earth, 6. —The chariot horses of Phœbus and the burden of the Sun, 7. —An unusual team, 7.—Gravity at the Sun's surface. A man crushed under his own weight, 8.—Slight density of the Sun, 9. —Sunspots and their rotation, 9.—The Sun's gaseous envelope. Solar hurricanes, 10.—Deviation of light by a prism, 11.—Dispersion, 12.—The solar spectrum, 12.—Spectrum lines, 13.—The light reaching us from the Sun is incomplete, 13.—The complete light from a white-hot ball, 14.—Effect of flames of metallic vapours, 14.—Physical constitution of the Sun, 15.—Its chemical composition, 15.

1. In order to find the distance between the Earth and the Moon we selected a base as large as possible consistent with the configuration of the continents, and from each end of that base we measured at the same distance the zenith distance of the Moon. The construction of a similar figure, or, better, a calculation, gave the value of the distance of the Moon in terms of the Earth's diameter. You might think that that method could be applied to any star whatever. But if we want to apply it to the Sun a great difficulty is presented by the slenderness of the base in proportion to the distance to be measured. Even in its greatest dimensions the Earth is nothing but a point if we wish to use it as scaffolding

for such an immense construction. Let us go back to Fig. 52 concerning the Moon, and suppose that the zenith distances DCL and HVL measured on the same meridian from two points C and V as far as possible from each other on the Globe are not concerned with the Moon, but with the Sun. We must now construct a similar figure with the angles found for the Sun.[1] Well, in this case the two lines *cl* and *vl* (Fig. 53) are immeasurably prolonged. The sheet of paper, however large, would not suffice for the construction. The two lines run along beside each other without meeting. We might almost consider them parallel. What does this result signify? It evidently signifies that the base CV from the extremity of Africa to the heart of Europe is in the present case without value. The Earth is too narrow for the geometrical edifice whose summit is the Sun. To measure the distance of that body with the dimensions of our Globe for a base is as ridiculous as it would be to base the triangle which is to give the distance of a tower several miles away on a line a few inches long. In the beginning we found our Earth very large, but you have no doubt changed your minds already. For the second step we are taking in the sky the diameter of the Earth is too short a stepping-stone. Geometry has no elbow-room on the surface of continents and seas. In our restricted world it has no scope for its operations. It must find it amid the spaces of the heavens, and it is there that we must look for a suitable base.

2. Such a base is at our disposal in the distance from the Earth to the Moon. Geometry must feel comfortable on a line comprising 60 times the radius of the

[1] We still use the construction of a similar figure for the sake of simplicity, but calculation would, of course, indicate the insufficiency of the base in its own way.

Earth. It would be so indeed if it could carry on observations from the two ends of that base, if from the Moon it could view the Earth on the one part and the Sun on the other just as it views the Sun and the Moon from the Earth. With the two angles thus obtained it would construct a similar triangle which would give us the distance from the Earth to the Sun, just as a triangle of which we know one side and two angles gives us the distance of a tower across a river. Unfortunately no geometrician's eye can go to the Moon and point a theodolite at the Sun and the Earth. We must, therefore, get round the difficulty and see that we have no need to measure the angle on the lunar station. For this purpose it suffices to observe by the phases of the Moon the moment when that angle is a right angle. The first man who had this ingenious idea was a famous astronomer of antiquity, Aristarchus of Samos. Grateful science has given his name to one of the craters of the Moon. Here is his method.

Let T be the observation post on the Earth, S the Sun, L the Moon (Fig. 61). At the exact epoch of the first or last quarter, that is to say the moment when the Moon just shows us half its illuminated hemisphere, we point at the centre of the Sun along one line, and at the division between light and darkness on the Moon along another line. This gives us the angle STL, the apex of which is on the Earth. As regards the angle TLS of the lunar station, it is known without being measured, since it is a right angle. As a matter of fact, in the circumstances we have chosen, the rays of the Sun are perpendicular to the line of sight TL, since we see exactly the half of the hemisphere which they illuminate. The line SL, which can be regarded as one of

these rays, is therefore perpendicular to TL. Thus, in the triangle TLS we know that LT is the length of 60 terrestrial radii, we know that the angle L is a right angle, and we know the angle T by direct measurement. This suffices for constructing a similar triangle, just as we did it in finding the distance of an inaccessible tower. We thus shall know how many times the line TS, which is the distance from the Earth to the Sun, contains the Earth's radius.

3. Although excellent in principle the method of Aristarchus is defective in application on account of the

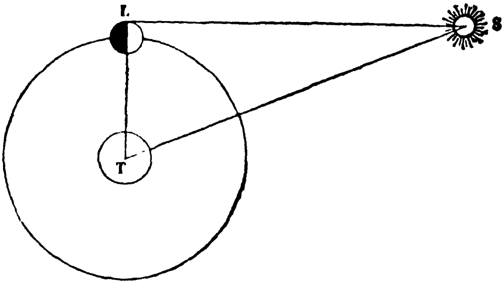


FIG. 61.

extreme difficulty of seizing the precise instant when the Moon shows us just half its illuminated hemisphere. The slightest error concerning that instant leads to results which are very far from the truth. Yet I have thought it best to mention this method because it is the only one you can now understand, and also because it shows you very clearly how one distance measured in the heavens may serve as a stepping-stone to measure a greater distance, which may again be used for measuring a third, and so on until, by means of all these steps, built one upon the other, astronomy scales the most inaccessible heights of the firmament.

The best method for determining the distance of the Sun is that of the transits of Venus. Let us explain this expression, which has as yet no meaning for you. You will soon learn that the Earth is not the only heavenly body which travels round the Sun. It has numerous companions, some of them smaller and some of them larger than itself. These are planets analogous to our own material globes endlessly rolling round the Sun and receiving from it their share of light and heat. One of these is called Venus. Its dimensions are just about those of the Earth, but it is nearer the Sun. In spite of its enormous volume that globe is only a small black point crossing the Sun's disk when it passes exactly between us and the Sun. If it were nearer to the Earth it would plunge us into shadow and would produce a total eclipse of the Sun, but at its present distance it only intercepts a small portion of the Sun and produces on its disk a round black patch too small to be seen with the naked eye. Transits of Venus are, therefore, appearances of perspective which show the planet crossing the Sun's disk like a small black point. Now, according to the station of the observer on the Earth's surface that black point seems to move higher or lower across the disk of the Sun, since the perspective of Venus changes with the change of the point of view. Now if two observers very far apart on the Earth each observe the apparent track of Venus across the solar disk, we may by combining these data with the distance between the two observing stations deduce the distance of the Sun.

4. The result of these researches is that our distance from the Sun is 24,000 radii of the Earth, or 93 million miles. In order to cover this distance and build a bridge whose first pile would be on the Earth and last pile on

the Sun we should have to assemble 12,000 globes like our own; it would require a chaplet of 12,000 beads each as thick as the Earth. None of us, however long our lives, could hope to reach the Sun some day with the very best means of locomotion, even if the journey were possible at all. His age would grow beyond the limits of human life, and he would be a centenarian more than twice over. Indeed, the fastest train on our railways constantly running at 63 miles an hour would take a century and three-quarters to cover the distance. A cannon-ball travelling 1,200 feet per second on leaving the mouth of the gun, or 900 miles an hour, would take over 12 years to travel from the Earth to the Sun if it kept its original speed.

This distance, combined with the angular diameter of the Sun, which is a little over half a degree,[1] enables us by the method explained above to calculate the real diameter, the radius, and hence also the volume of the Sun. We thus find that the radius of the solar globe equals 112 radii of the Earth, and that the Sun's volume could contain 1,400,000 globes like the Earth.[2]

According to these numbers, if we suppose the Sun to be hollow, like a spherical shell, we should have to pour into it 1,400,000 balls the size of the Earth. Or again:

[1] The mean diameter is 32 minutes 6 seconds. It is called mean because the Earth is not always at the same distance from the Sun, and this makes the angular diameter of the latter vary.

[2] Geometry proves that a sphere whose radius is 2, 3, 4 times larger than another has a volume 8, 27, or 64 times greater, respectively. The numbers 8, 27, 64, etc., are what are called in Geometry the "cubes" of the numbers 2, 3, 4, etc., meaning these numbers multiplied three times by themselves. Thus 64 is $4 \times 4 \times 4$. To compare the volume of the Sun with that of the Earth we should, therefore, have to take the cube of 112. The result is 1,404,928. If we only take the first two significant figures we get 1,400,000. This simplification is permissible. What are a few thousand Earths when we are dealing with the Sun!

if the centre of the Sun occupied the point in space where the Earth is situated that colossus would enclose the Earth, which would be almost lost in the immense volume, and its surface, reaching beyond the region of the Moon, would extend almost as far again. In fact the distance from the Moon to the Earth is 60 times the Earth's radius, and double this is 120. But the radius of the Sun is 112, which is little less than 120. Let us try a last comparison. In order to fill up the measure of capacity called a quart we require about 10,000 grains of wheat. We should, therefore, require 100,000 to fill 10 quarts, and 1,400,000 to fill 140 quarts. Now imagine we have a heap containing 140 quarts of wheat and a single grain beside it. That single grain will represent the Earth, and the heap of 140 quarts, or 35 gallons, will represent the Sun.

5. Astronomy is not content with those admirable results. After finding the distance and volume of the Sun it tackles the determination of the quantity of matter contained in that luminary, or what is called its mass, or the number of times its weight exceeds that of the Earth. We know very well that the Sun is 1,400,000 times more voluminous than the Earth, but that tells us nothing about its weight, since a ball of pith, for instance, can be bulkier than a ball of lead, and yet weigh less. Since the volume teaches us nothing concerning the quantity of matter we have only one means of determining the Sun's mass, and that is to weigh it. When I talk of such a problem you smile incredulously. To weigh a body 93 million miles away seems to you a foolish presumption. Yet you should remember that we have weighed the Earth just as if it were possible to put it on the pan of a balance. In

this case, in spite of the distance, the problem is even simpler. We know that a globe encloses 2, 3, or 4 times more matter than another when it makes the body fall 2, 3, or 4 times faster at the same distance. Thus the question reduces itself to that of determining how many times quicker a body falls towards the Sun than towards the Earth, the times and distances being supposed equal.

A body falling on the surface of the Earth covers a vertical distance of 16 feet in the first second. If the fall, instead of being on the surface of the Earth, took place at a distance equal to 24,000 times the Earth's radius; in other words, if the body were as far away from the Earth as is the Sun, its fall would be diminished in proportion of the square of the distance, and would become $\frac{16}{24{,}000 \times 24{,}000}$. Without carrying out the calculation let us represent that value by m. We must now find experimentally the amount of fall towards the Sun. The movement of the Earth makes this possible, though it looks impossible at first sight.

6. Let us go back to Fig. 56 of the Thirteenth Lesson, but change the significance of the letters so that T is the Sun and L the Earth revolving round the former in an orbit of 93 million miles radius. In one second the Earth passes from L to B, for instance. It thus falls towards the Sun by a quantity AB, a quantity which we can calculate exactly from the size of the Earth's orbit and the time taken to complete it. Thus in one second and at that distance of 93 million miles the fall towards the Earth is equal to that quantity m above mentioned, and the fall towards the Sun equals the quantity AB. After making all calculations we find that the first quantity is contained 354,936 times in the

second. Hence the mass of the Sun equals 354,936 times the mass of the Earth, since at the same distance it makes bodies fall so many times faster.

One point in this demonstration will perhaps appear to you to have insufficient foundation. Though everything may be reduced to the same distance, it might seem that we were comparing falls which are not similar. In the one case it is the fall of a terrestrial body, transported in imagination to the distance of the Sun, while in the other case it is the fall of the Earth itself, with all its heavy weight. Now, must not the Earth, being immensely heavier, fall more quickly than a terrestrial body, even as large as a mountain? No. Take a handful of pebbles and open your hand. The pebbles fall side by side, they descend together and reach the Earth at the same time, since they go with the same speed. Everything happens as if they were linked together and formed a single body. Therefore a ball equivalent to the whole of the pebbles taken together would not fall quicker than any one of them. Here is another comparison. A horse draws a load. If the load is doubled and is drawn by two horses, would the speed be greater? Evidently not. If the load is trebled and the number of horses is three, will the speed be changed? No. Well, every pebble is a harnessed horse and the mass of the pebbles is the load to be drawn. If the force is increased by making a pebble into a ball equivalent to 10, 100, or 1,000 pebbles, the fall will not be changed because the load set in motion will have become 10, 100, or 1,000 times heavier. Indeed, a grain of sand and the Earth fall with the same speed provided that the fall takes place under the same conditions.

7. Antiquity, with its crude ideas, imagined the Sun

to travel through the sky drawn by four horses—Eous, Pyrous, Ethon, and Phlegon—whose eyeballs and nostrils emitted fire. I do not know on what pasturage of Olympus the four chariot horses recruited their forces; but in any case they had plenty of need for it. Let us make the quaint assumption that the Earth is placed in a chariot and is dragged along a surface corresponding to our roads. What must be the team to draw such a load? The answer is obtained by calculation. Let us harness a million horses in front, and let us put in front of them again a second million, and then a third million. Let us proceed in this way until we have 100 million, and then 10,000 million. There are no pastures on earth which would feed our team of 10,000 million horses. And now let us whip them up. Nothing moves. The force is insufficient. We can well believe that nothing moves, for in order to move the burden of the Earth we should require 10 million of such teams. And what about the Sun, which is 354,936 times heavier? Ah, poor horses of the fable, charged with dragging the chariot of Phœbus, you may be strong, but could you roll the Sun of science over the plains of the heavens? Those whose childish imagination gave you that task saw nothing in the colossal luminary but a large disk like the wheel of a knife-grinder. But let us put away these follies and forget Olympus, Phœbus, and his horses. Only one power moves this inconceivable mass in space, the finger of God.

8. From the mass and radius of the Sun we can deduce the force of gravitation on the surface of that body. The calculation is very simple. If the Sun condenses all its matter in a globe equal in volume to the Earth, it would attract bodies on its surface with a force 354,936 times

greater than the Earth itself. But since its radius is 112 times greater, we must diminish that first result in proportion with the square of the distance from the centre, and must divide it by the square of 112, which is 12,544. Then we obtain the number 28. Therefore, on the surface of the Sun, gravitation is 28 times greater than on the surface of the Earth, and this means that a body falling without hindrance at the Sun's surface travels in the first second of its fall 28 times 16 feet, or 448 feet. It means that an object weighing 1 lb. here would weigh 2 stone up there, without any increase of substance. It would weigh more even while it was the same object, because it is more strongly attracted. This shows us what a sorry figure we should cut on the surface of the Sun. As we are organised, we valiantly bear the weight of our bodies. We go about without being embarrassed by our weight because our forces are in harmony with the weight of our body. But on the Sun our forces would not be increased, but our bodies would be 28 times heavier. We should be in the position of a man who tried to carry 27 other men on his shoulders. Overwhelmed by our weight, we should be nailed to the surface of the Sun, or rather we should be crushed under our own weight as a firkin of butter, which is too heavy and too soft, subsides and spreads over its base.

9. Prodigious as it is, the mass of the Sun is not as great as its volume would indicate. If the material of that body were uniformly distributed every gallon would weigh 14 lb., which is hardly above the weight of water. We know that a gallon of the average surface material of the Earth weighs 55 lb. The lightness of the matter of the Sun, taken as a whole, is explained by supposing that the Sun consists of a great gaseous envelope with

an excessively high temperature on the outside, and denser matter, either liquid or solid, at the centre. The gaseous envelope, while exaggerating the volume of the Sun, would not increase the weight to the same extent, and this would explain the relative feebleness of the mass. This supposition is confirmed by atmospheric evidence. If the Sun is observed with a telescope provided with a smoked glass to moderate the glare and heat of its rays, we often see on the surface of the Sun a certain number of spots with very irregular outlines, which stand out vividly on the luminous white surface by their intense blackness. They are usually surrounded by a greyish rim, improperly called a "penumbra." These spots are movable. They appear on the extreme edge of the Sun, advance gradually on the disk, moving from west to east, reach the opposite edge, and disappear, showing themselves again on the other edge in less than a fortnight. It has been concluded from these periodic returns of the same spots that the Sun turns on its axis in 25½ days. A spectator placed on a point in its axis with his head towards the upper pole would see the Sun turning from his left to his right. He could see the Earth revolving round the Sun in the same direction.

10. The sun-spots are not permanent. At one time they are in great numbers, and at another there are none. Some are formed under the eye of the observer, like storm clouds in our own atmosphere. Others are torn off in pieces, which group themselves in new configurations, or dissolve and disappear in the luminous background. Others of greater stability are brought round under our eyes in the same general aspect by the rotation of the Sun, but it is only rarely that they retain the same shape for several successive periods of rotation.

Some precise measurements tell us of their gigantic dimensions. Some of them have a surface larger than that of the entire Earth. Herschell observed some which were 4,800 miles wide. What are these spots? Perhaps they are chance collections of darker matter which revolve in whirlpools and dissipate themselves in an ocean of fire. Perhaps they are holes opening in an envelope of flames, and allowing us to see the dark interior. But let us leave these premature suppositions. The Sun has not yet revealed its secrets. One point, however, cannot be doubted. These enormous spots which form and dissolve in a few hours or days are made of some material which is subject to tremendous upheavals, and offers but little resistance to them. The surface of the Sun is the seat of profound convulsions, hurricanes, cyclones, and tempests, which tear up the substance of the Sun and carry it along in an endless storm. We are therefore led to the same conclusion, viz. that the Sun has an external gaseous envelope in a state of incandescence.

11. From the detailed study of light science is able to infer the nature of the source of light. It is able to teach us of what materials the Sun consists just as if it were able to put a portion of it into its crucibles. Let us examine in an elementary way these marvellous researches on a ray of sunlight.

A beam of light penetrates into a dark room through a hole in the shutter. Nothing special happens under those conditions. The beam of light traces out a perfectly straight line in which specks of dust suspended in the air shine and dance about. A plate of glass interposed in the beam does not make it undergo any remarkable change: the beam of light penetrates the transparent glass and pursues its straight path on the

L. A SUNSPOT 100,000 MILES ACROSS.

3 February 1905.

[*To face p.* 198.

other side. But if the piece of glass, instead of being flat like a plate, is cut in the form of a corner, or what we call a prism, the luminous beam, instead of describing a straight line, proceeds suddenly in a new direction after traversing it. The refraction produced twice in succession by a double change of medium is the cause of that deviation.

Let us take a prism ABC (Fig. 62). A beam of light hits it along the line SI. Since it passes from air into glass, or from a less dense medium to a denser medium, it approaches the perpendicular NO on entering the

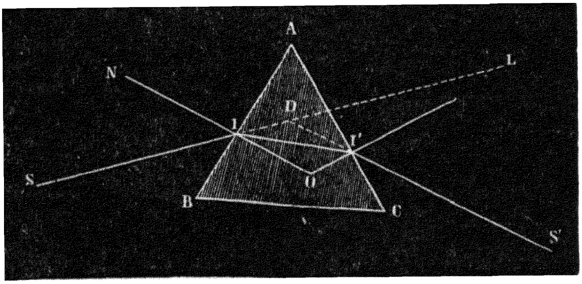


FIG. 62.

glass, and instead of following its original direction IL it takes the direction II′, which is nearer the perpendicular. On reaching I′ it passes from glass into air, or from a denser medium into a less dense medium. It therefore shifts away from the perpendicular N′O and takes the direction I′S′, which makes with the perpendicular an angle N′I′S′, which is greater than the preceding angle II′O. Thus it happens that in traversing a prism a beam of light changes its direction twice and approaches the base of the prism.

12. Beside that deviation the light suffers another and very important modification in passing through the

prism. The luminous beam, moulded by the orifice through which it enters the dark room, retains its shape and size until it reaches the prism, but in penetrating into the glass it is enlarged. It is enlarged still further on emerging from the prism, and spreads out like a fan (Fig. 63). The deviation is therefore not the same for the whole of the original beam, since the latter, after traversing the prism, spreads out into a sheet comprising a large number of different directions. In other words,

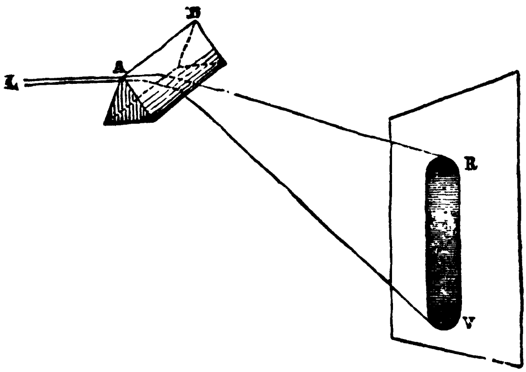


FIG. 63.

sunlight is not homogeneous, and is not the same over the whole of the beam. If that homogeneousness existed, the effect of the prism, whatever it was, would be the same for the whole of the beam, so that the latter while changing its direction on leaving the glass would keep its original form instead of spreading out.

But let us proceed to interpose a sheet of white paper in the path of the luminous beam as spread out by the prism (Fig. 63). We at once observe an oblong figure on the paper glowing in all the colours of the rainbow: violet, indigo, blue, green, yellow, orange, and red. This

oblong figure is called the " solar spectrum." The word spectrum simply means image. Nothing could be simpler than the explanation of the solar spectrum. Sunlight is not homogeneous. Its different elements or rays in traversing the prism undergo deviations which are stronger for some and feebler for others. They separate from each other, and each of them paints the screen with its own colour. Hence the succession of spectrum colours. We see, therefore, that ordinary daylight and the white light of the Sun contain differently coloured rays. They may be violet, blue, green, yellow, etc. When these elementary rays are assembled in one bundle they constitute white light. If they are separated by a prism each of them resumes its proper tint. The solar spectrum not only includes the seven colours enumerated above, but also all the intermediate shades, with such fine gradations that it is impossible to say, for example, where green ends and yellow begins. White light comprises in reality a mass of rays of different colours, which are unequally deviated by a prism. The solar spectrum is, therefore, a sort of keyboard of colours, including all shades from violet to red, just as the keyboard of a musical instrument includes all the notes from the lowest to the highest.

13. Let us examine this coloured keyboard a little more closely. With the aid of magnifying glasses we can see that the luminous band of the spectrum is crossed by a very large number of lines in which the light goes out. These interruptions take the form of parallel lines of an intense blackness, which are finer or coarser, closer together or farther apart, according to the portion of the spectrum we are examining (Fig. 64). Their number is invariable, and so is the order of succession. They are

indelibly characteristic of the solar spectrum, and are found at all times and everywhere in the same place. Physical science calls them spectrum lines. What is the meaning of these dark lines which interrupt the light ? If sunlight included every possible ray from the extreme violet to the extreme red, all possible places in the spectrum band would be occupied, since every sort of deviation would be realised by the effect of the prism, and there would be no interruption from one end of the spectrum to the other. But if some elementary rays are absent, the prism must show this defect by void

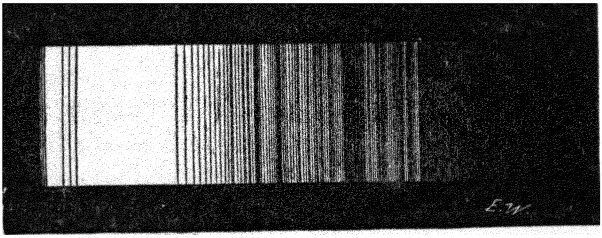


FIG. 64.

spaces, by dark lines, or the unoccupied places of the absent rays. The dark lines of the spectrum, therefore, signify that the light of the Sun reaches us in an enfeebled state, apparently because some of its rays are extinguished on the way. Using the previous expression, we can say that this coloured keyboard of the spectrum is imperfect. It lacks numerous rays whose vacant places are indicated by black grooves.

The light which reaches us from the Moon and the various heavenly bodies illuminated by the Sun gives the same result. The spectrum is always interrupted by a large number of black lines which succeed each other

in the same order as they do in the solar spectrum. This is quite natural. Moonlight is reflected sunlight, and must therefore be stamped with its indelible character. As regards the stars, which are distant suns analogous to our own, they give, on the whole, spectra resembling those of the Sun, in that they are crossed by numerous lines. Yet for each star the lines are different and differently grouped. The rule is, however, general; the luminous stars of the sky, when subjected to prismatic examination, all give spectra crossed by lines. Their light is incomplete, and the gamut of their colours lacks several notes, and the absent notes, which are invariable for each, are variable from one star to another.

14. To find an imperfection in the grandest of the world's splendours, the rays of the Sun, is a result of considerable importance. Once this imperfection is found, we feel bound to investigate its cause. And in the first place, is it possible to obtain perfect light? It is, because all that is necessary is to take an incandescent solid body for our source of light, such as a white-hot ball of metal. If we direct a luminous beam from such a body across the prism we obtain a spectrum of perfect continuity, without a trace of dark lines. In that luminous pencil the elementary rays are complete, since all their places in the spectrum band are occupied. But we can easily produce vacant places. Take a strong flame, such as that of a gas-burner, or, still better, a flame of alcohol. Let us sprinkle this flame with a fine metallic powder, or iron filings, and through this flame let us pass the beam of light from the white-hot ball before it enters the prism. Remember the arrangement of the apparatus. On one side we have the white-hot ball which radiates perfect light, on the other side we

have the prism which must decompose the luminous band, while between the two we have a flame which burns metallic powder. In order to pass from the ball to the prism, the pencil of light must traverse the flame with the metallic vapour. Now with such an arrangement we find that the spectrum is not complete. We find that it contains several black lines similar to those of the solar spectrum, but much less numerous. We carefully observe their number, their place, and their arrangement. Then we proceed to throw into the flame a powder of another metal, such as copper. The spectrum is again crossed by lines, but the lines are different from those given by the iron, both in their number and in their manner of grouping. With lead, silver, tin, gold, zinc, etc., new lines appear which vary in number and position from one metal to another, but remain the same for each metal. Thus, when the pencil of complete light traverses the flame in which any metal is burning, it suffers a partial extinction which deprives it of some of its elementary rays, and that loss is shown in the spectrum by dark lines whose situation, number, and arrangement depend on the nature of the metal.

15. In order to apply these data of experience to sunlight, let us follow science in assuming that the Sun is composed of a central globe, liquid or solid, rendered luminous by excessive heat, a degree of heat far beyond the most intense heat we can produce artificially. Round this radiant nucleus there is a gaseous envelope of immense extent, a sort of atmosphere of substances volatilised by the heat. Here we have not, as in the case of the Earth, a blue dome of air, veiled with clouds which drop down rain. It is an envelope of flames, a prodigious mass of blazing metallic vapours, falling in showers of molten

metal, evaporating again, and indefinitely reproducing its terrible cataracts. From the central globe light radiates out in a perfect condition as does the light of the white-hot ball in our experiment, but in traversing the flame envelope it loses a portion of its elementary rays. It therefore reaches us incomplete, and the numerous black lines of the spectrum which it produces are the result of the vaporised metals in the Sun's atmosphere. Some of these metals are known to us. We find, indeed, in the solar spectrum lines characteristic of the flame in which we burned iron. Their number and grouping leave no room for doubt. There is, therefore, iron in the Sun's flaming envelope. There are, also, copper, zinc, and other terrestrial metals, for the dark lines corresponding to these various metals are found to be identical with those in the solar spectrum. On the other hand, the presence of lead, silver, or of gold has not yet been traced. Also there is reason to believe that the atmosphere of the Sun includes metallic vapours corresponding to nothing known on Earth, for many dark lines of the solar spectrum do not coincide with any that are produced by terrestrial substances.

This rapid survey of the spectrum study of light, or spectrum analysis, leaves us with one great idea. The earth possesses, perhaps, some metallic substances which are all its own, and the Sun is in the same case, but at a distance of 93 million miles there is between the two bodies an undoubted chemical relation. The Earth and the heavens are built of the same materials. This conclusion, as we shall see, is confirmed by shooting stars.

SIXTEENTH LESSON

THE YEAR AND THE SEASONS

The Earth's translation, 1.—Tracing an ellipse, 2.—The Earth's orbit. Perihelion and aphelion, 3.—Solar day and sidereal day, 4.—The solar day longer than the sidereal day, 5.—The heavens renewed from one season to another, 5.—Solar year and sidereal year, 5.—Variability of the solar day, 6.—Unequal speed of the translation of the Earth, 6.—Experiment of the wheel and the lump of lead, 7.—Mean solar day, 8.—The Earth's axis keeps parallel to itself, 9.—Inclination of the Earth's axis and the seasons, 9.—Days and nights at the June solstice, 10.—Explanation of their inequality, 11, 12.—Day and night at the poles, 11, 12.—The Arctic Polar Circle, 11.—The Antarctic Polar Circle, 12.—Influence of obliquity on the solar rays, 13.—Summer and winter, 13.—The tropic of Cancer, 14.—Days and nights at the December solstice, 15.—The tropic of Capricorn, 15.—Equinoxes, 16.—Unequal duration of the seasons, 17.—Table of longest days from the equator to the pole, 17.—Zones, 18.—The top and the conical swing of the Earth, 19.—The great period of 26,000 years, 19.—The Pole Star in 12,000 years' time, 19.

1. DRIVEN by its original impulse, and maintained in an immutable orbit by its perpetual fall towards the Sun, the Earth revolves round that dominating body just as the Moon revolves round us. In one year, or a little over 365 days, it accomplishes its voyage only to recommence it indefinitely. With a speed of 67,000 miles per hour, the terrestrial ball rolls through space without any support or pivot, always on that imaginary line which a divine geometry has given for its guidance. Its movement is so rapid that it makes us giddy to think of it. It is so silent that the meditations of science alone

can prove it to be true. To maintain its speed and keep it always at the same distance from the central star from which it receives its heat, its light, and its life, an exact balance between the attraction of the Sun and its own impulse suffices. If the former were to give out, the Earth, carried away by its own impulse, would abandon the Sun and rush away in a straight line and would be shipwrecked in the unknown spaces of the heavens. If the Earth's impulse, on the other hand, were suspended, the Earth would fall into the colossal star which attracts it. In 64 days the 93 million miles which separate us from the Sun would be traversed, the fall would have taken place, and our Globe would plunge like a tiny smut into the mouth of the solar furnace. Or again, if the original impulse, instead of suddenly vanishing, were to be gradually weakened, by a resistance, for instance, the Earth would not describe a curve returning on itself, but a spiral, whose turns would become ever narrower, and finally bring it by a whirling movement into the Sun. These are gratuitous suppositions. There is nothing which threatens to oppose or retard the Earth's impulse, nothing which threatens to paralyse the Sun's attraction. The stability of our orbit is assured for ever.

2. The Earth's orbit, which we have hitherto, for the sake of simplicity considered circular, is really more complicated than that. It is an ellipse, and not a circle. In order to trace an ellipse on the blackboard, we must proceed as follows. Fix two nails in the board. To the two nails tie a string, which you leave very slack. With a piece of chalk held against the string, stretch out the latter and then make the chalk travel into every possible position while keeping the string

always tight (Fig. 65). The line thus described is called an "ellipse." Two points, F and F′, where the ends of the string are fixed, are called the foci. The line AB is called the major axis of the ellipse, and the line DE is called the minor axis. If we join any point M of the ellipse to the two foci, each line MF, MF′ is called a "radius vector." It is clear, according to the mode of tracing the ellipse, that the sum of the lines MF, MF′ is always equal to the length of the string FCF′, whatever may be the point M. We may therefore define an ellipse as follows: An ellipse is a curve such that the sum of

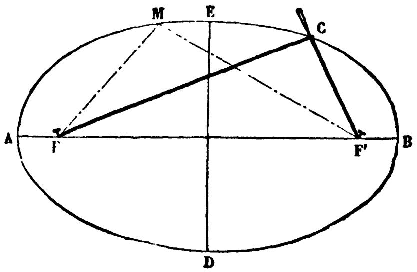


FIG. 65.

the distances of each of its points from two points called foci is constant. The farther the foci are distant from each other for the same length of string, the more does the ellipse spread out and differ from the circle; if, on the other hand, the two foci become one, the curve described becomes a circle.

3. The orbit traversed every year by the earth is an ellipse in which the Sun occupies one focus. Its shape, however, is round enough for us to regard it as a circle for ordinary purposes. In the same way, the Moon revolves round us in an ellipse, of which our Globe is a focus. But since the Earth itself moves, the Moon, in

order to accompany it, must necessarily move its orbit, which thus becomes a series of parts of ellipses strung together. But the rule is general: every heavenly body obeying the attraction of another, revolves round the latter in an ellipse, and one of the foci of the orbit is occupied by the attracting body.

With its elliptical orbit, the Earth is not always equally distant from the Sun; the distance is smaller when the Earth occupies the extreme end of the major axis nearest the Sun, that is to say, the point A (Fig. 65), when the Sun is at the focus F. This point is called the "perihelion." The distance is greatest when the Earth reaches the opposite extreme, the point B, which is called the "aphelion." [1]

Our voyage from the perihelion takes place on the 31st of December, and we pass through the aphelion on the second of July. The strange consequence of this is that we are nearer the Sun in winter than in summer. The difference of the distance is about 2,750,000 miles.[2]

4. While being carried round the Sun in its elliptical orbit, the Earth turns on its own axis. The duration of each of its rotations is called a "day." Two kinds of day may be distinguished: solar day and sidereal day. The sidereal day is the duration between two consecutive returns of the same half-meridian to the same star. Its amount is invariable, since the Earth, turning upon its axis with a speed which nothing can modify, brings each point of its surface to face the same point in the sky at precisely equal periods. We have

[1] Perihelion means near the Sun, aphelion away from the Sun.

[2] The elliptical movement of the Moon explains why it is sometimes nearer to us, and sometimes farther away. We have already said that the smallest distance of the Moon is 56 radii of the Earth, and the largest 64 radii.

seen, in another lesson, that in the course of 20 o 25 centuries Astronomy has found no change amounting to one-tenth of a second in the duration of the sidereal day. And that is inevitable. The sidereal day is in some way the measure of the mechanical energy of the Earth, moving about its axis. That energy cannot be dissipated in the absence of all resistance, and so the rotation maintains a constant speed.

The solar day is the time comprised between two consecutive passages of the same half-meridian in face of the Sun. If the Earth simply turned on its axis without moving in space, the solar day and the sidereal day would have the same duration. Every point of the Earth's surface, in order to come again to the same star or the Sun, would require the same time. But the translation of the Earth interferes with that equality. We have something corresponding to what I have already told you on the subject of the synodic revolution and the sidereal revolution of the Moon.

5. Let us consider the Earth in position 1 of Fig. 66. At that moment the meridian AB is facing the Sun S on one side. On the other side, it faces a certain star which is infinitely far away in the direction BE. For the illuminated half of this meridian, it is midday; while for the other half it is midnight. Next day, the Earth has moved farther along its orbit, indeed very far, since it moves at the rate of 68,000 miles an hour. Thus it occupies position 2, for instance; and the same meridian A′B′ is brought back by the rotation of the Earth to face the original star, which is in the direction B′E′, parallel to the direction BE of the previous night. This expression "parallel" is not exaggerated. I repeat: The stars are so prodigiously far away that the distance

covered by the Earth in one day, or even in whole months, is like nothing in comparison with their own distance. Whether in position 1 or in position 2 the Earth will see the star in the same perspective, just as if it had not changed its place. But it sees the Sun, which is much

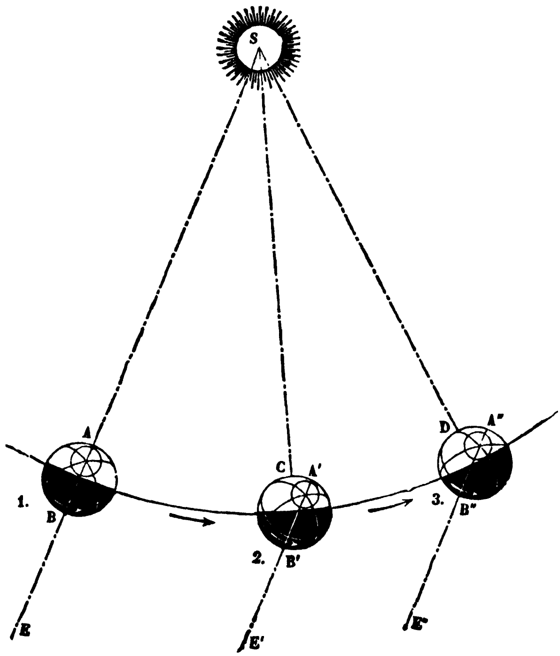


FIG. 66.

nearer, in a changing perspective. And so the meridian A′B′, for which we have completed the sidereal day, since it faces the same star, has still to turn a little, by the amount A′C, to find itself facing the Sun. Thus the solar day is always longer than sidereal day, the difference amounting to about 4 minutes.

A star which to-day passes over our heads at the same

time as the Sun, and is invisible on account of the bright sky, will to-morrow pass 4 minutes earlier, and the next day 8 minutes earlier, and so on, so that at the end of 6 months, by the culmination of its daily advances of 4 minutes, it will come back to us at night and will pass overhead 12 hours before the Sun, and will be quite visible. Thus we can explain the changes in the aspect of the stars of the sky. In the summer, certain constellations are visible, while in the winter others replace them, and gradually, from year's end to year's end, all the stars pass through our nocturnal sky. If the solar day and the sidereal day had the same duration, nothing of the kind would happen. The same stars would always accompany the Sun, and half of the sky would be unknown to us, being perpetually filled by the brightness of sunlight. Only the other half would show us its constellations every night. This renewal of the starry sky with their seasons furnishes us, therefore, with a new proof of the translation of the Earth.

At the end of 6 months the stars accompanying the Sun find themselves in advance by 12 hours. This advance increases every 6 months, until it becomes 24 hours, and the completion of this circuit brings the original stars over our heads with the Sun at the same time. Thus a period is finished, and another commences. The Earth comes back to the same point in its orbit, and the year is finished. In that period the Sun has apparently passed round the Earth 365¼ times, while the stars, being faster, have passed round 366¼ times. Thus the year has 365¼ solar days, or 366¼ sidereal days.

6. The solar day does not only differ from the sidereal day by an excess of duration, but by another remarkable characteristic. The sidereal day is invariable in length,

while the solar day varies, being sometimes long and sometimes short, according to the time of the year, though it is always longer than the sidereal day. The excess of 4 minutes which I mentioned just now is only a mean value, that is, a value intermediate between all the possible values of the excess of length from year's end to year's end. Among the causes of the variation of the solar day, the following one is easy to understand.

We have supposed (Fig. 66) that during one rotation on its axis the Earth is transported from position 1 to position 2, and the excess of the solar day over the sidereal day was attributed to the displacement suffered by the meridian A′B′ when brought to face the same star in the direction E′, in order to pass from A′ to C and be brought to face the Sun. Let us suppose that the Earth travels more rapidly on its orbit, and is transported in one rotation not from 1 to 2, but from 1 to 3. In this case, when the sidereal day has finished, that is when the meridian will have taken the direction A′E′ parallel to AE, and will have thus been brought to face the same star, there will still be at the point A″ the arc A″D to traverse in order to face the Sun. But it is obvious that the arc A″D is larger than the arc A′C. Thus the solar day is longer when the Earth, in the interval of a rotation, is transported from 1 to 3, than when it is transported from 1 to 2. And generally, as the Earth moves more rapidly in its orbit, the solar day lengthens out, since the meridian must turn more to come under the Sun, which is farther away on account of the movement of the Earth. In order to demonstrate the variation of the solar days, it is sufficient to show that the Earth varies in speed while revolving round the Sun.

7. We might think that, because of the complete conservation of its mechanical energy, the Earth ought to travel in its orbit with a constant speed. That would, indeed, be the case if the orbit were a circular one. The perfect symmetry of the arcs traversed daily would imply the equality of the times required to traverse them. But this is not the same with an elliptical orbit, which sometimes removes the Earth away from the focus occupied by the Sun, and at other times bring it nearer. A few experiments will make this clear.

Let us imagine a very light vertical wheel which can turn on its axis by means of a handle. To one of its spokes a heavy lump of lead is attached, either near the shaft or near the rim of the wheel, or at any intermediate position we please. Let us first fix the lump of lead as near as possible to the shaft, and let us find what speed we can impress upon the wheel by hand. By employing all our force we can, let us suppose, give the wheel a speed of one turn per second.

Let us repeat the experiment, after sliding the lump of lead on its spoke and fixing it near the circumference. In this new state the wheel weighs neither more nor less than it did before, and the lump of lead is the same, only it is farther away from the centre of rotation. The quantity of matter in the wheel is the same as before, and yet what do we find? The hand, which just now could give the wheel one turn per second, finds it very difficult to move the wheel at all, and does not succeed in giving it its previous speed. With the same force we cannot obtain one turn per second!

If you cannot construct this curious apparatus, which turns more or less quickly under the force of your hand according to the distance of the lump of lead from the

shaft, I recommend to you the following experiment. Attach a bullet to the end of a thread, seize the end between two fingers, and swing the bullet round like a sling so that the thread is rolled up on a third finger. You will then see that the bullet turns more and more quickly as the thread shortens, being wound on to your finger. Thus, in turning round a centre, under an impulse of constant amount, a body moves faster when near the centre, and more slowly when away from it.

8. On account of the elliptic form of its orbit, the Earth is not always equally far from the centre around which it turns. It approaches the Sun in the winter and moves away from it in the summer. Its speed of translation is, therefore, variable, being more rapid at the perihelion at the end of December, and slower at the aphelion, in the first days of July. These unequal displacements of the Earth according to the time of the year in the interval of one rotation are the partial cause of the inequality of the solar days.

Our clocks and watches have movements which are necessarily uniform. They cannot, therefore, faithfully follow the Sun, which reaches our meridian in variable periods. A watch which to-day marks noon at the moment when the Sun passes the meridian will not be in agreement with the Sun to-morrow or afterwards. It will show noon a little before or after true noon, a little before or after the real passage of the Sun through the culminating point in its journey through the sky. How, then, can we know the hour amid these continual variations? It has been agreed to adopt as the unit of time a fictitious day, called the "mean solar day" It is obtained by dividing the total duration of the solar year into 365 equal parts. The unit thus obtained has

the advantage of perfect regularity as required by our clocks, though it has the inconvenience, not a very serious one, of being rarely in accordance with the actual position of the Sun. A watch regulated, as all watches are, by mean time is sometimes in advance and sometimes slow with regard to the Sun. The greatest difference, more or less, can amount to a quarter of an hour. The sidereal day, on account of its inflexible regularity, is frequently used in Astronomy, but it cannot be used for any ordinary purposes. It would, in fact, be a strange distribution of time which, counting from the passage of a certain star across the meridian, would give us noon in the morning, in the afternoon, at midday, and at midnight in turn.

9. A ball thrown by hand and rolling on the ground turns without any regularity, sometimes about one axis, sometimes about another, according to the resistance it encounters. What was a pole of rotation may, sooner or later, be on the equator, or a point on the equator may become a pole. The ball has a disordered course, raising or lowering its axis or reversing it without finding a position of equilibrium. Thrown by the Divine Originator, the ball of the earth rolls through the fields of space on a constant axis. Never will its poles pass through the equator, and never will the equator follow the lines of the poles. It is for ever stabilised on an immovable pivot, and this imaginary pivot, this axis of rotation, not only is always the same, but it retains a fixed position, remaining parallel to itself for the whole annual voyage of the Earth. It never rises into an upright position, and it never increases its inclination, at least not within the limits to which I am about to refer. To-day it points at a certain star, the Pole Star, and

to-morrow and the next year, and for many long years to come it will be the same. In keeping its axis parallel to itself in an invariable direction, the Earth obeys the laws of inertia. It turns in a medium without obstacles and without resistance, on an axis whose alignment cannot change. Let us add that the Earth does not rotate upright before the Sun, but that its axis is somewhat inclined in one direction, but always the same

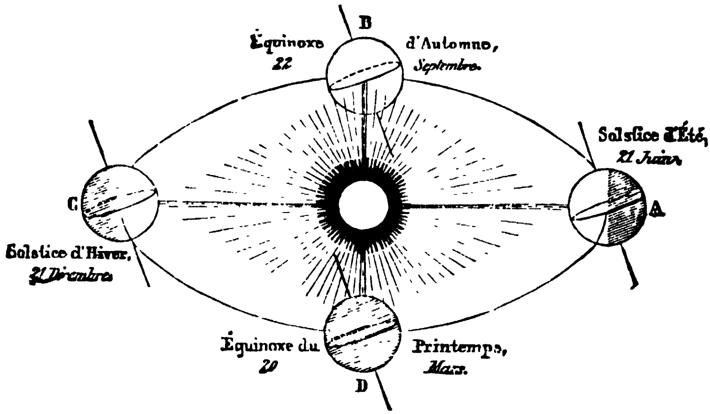


FIG. 67.

direction. This deviation from the upright position is 23½ degrees.

Now the annual revolution of the Earth, combined with the parallelism and inclination of its axis, is the cause of the seasons. Fig. 67 represents the four principal quarters which the Earth occupies in its orbit in the course of the year.[1] It is at A, near the aphelion, at the commencement of summer on the 21st of June, and it

[1] In this diagram, the terrestrial orbit is represented without inconvenience by a circle seen in perspective with the Sun in the centre. Strictly speaking, it should be an ellipse with the Sun in one of the foci.

is at B at the commencement of autumn on the 22nd of September; it is at C, near the perihelion, at the beginning of winter on the 21st December, and at D at the beginning of spring on the 25th of March. Summer includes the time taken by the Earth to describe that part of its orbit situated between A and B; autumn corresponds to the portion BC, winter to CD, and spring to the portion DA. Before going farther, we must carefully note on the diagram that the axis of the Earth is everywhere inclined to the same extent and in the same direction. Also that throughout its orbit it remains parallel to itself.

10. That being so, we must suppose that we are in the last days of June. At no other time of the year does the Sun rise so early. At 4 o'clock in the morning it rises, and at 8 o'clock in the evening it sinks below the horizon.[1] At noon it is not just over our heads, but nearly so. In order to see it we must raise our heads nearly to the zenith. How bright it is then, and how hot! Its nearly blinding rays flood the atmosphere and cast treasures of heat into the soil. It is for us the time of the longest days and shortest nights, days of 16 hours and nights of 8 hours. In going farther north we should see the day lengthen even more and the night shorten. We should find countries where the Sun rises earlier than here, rises at 2 a.m and sets at 10 p.m. Farther north it would rise at 1 a.m. and set at 11 p.m. Others again where the hours of rising and setting are confounded so that the day star hardly touches the horizon and rises again immediately. Finally, near the pole we should find the curious spectacle of a Sun which no longer sets,

[1] Where summer time is in force these hours are 5 a.m. and 9 p.m. respectively.—Tr.

but revolves round the spectator for whole weeks and months without disappearing in the horizon, equally visible at noon and at midnight. In these countries there is no more night.

In the southern hemisphere of the Earth we should find the opposite : a Sun without brightness, low temperature, shortened days, longer and longer nights. Finally, at a certain distance from the South Pole the night would be continuous. Towards the end of June the two halves of the Earth are therefore in opposite states. The northern half has long days, short nights, bright light, high temperature, and its pole is continually in the rays of the Sun ; the southern has short days, long nights, light without brightness, cold temperature, and its pole in perpetual night. For the former it is summer, and for the latter it is winter.

11. It is easy to account for this unequal distribution of solar rays between the two poles of the Globe. Fig. 68 shows the Earth as it presents itself to the Sun when it occupies the position A of the preceding figure ; that is, on the 21st of June. The Sun's rays are shown by a set of dotted lines. I have already said, and this diagram shows it more clearly, that the axis is inclined to the direction which joins the Earth to the Sun, so that the Earth, instead of turning upright in the presence of the Sun, turns while inclined to one side. This inclination of the axis brings it about that the line separating light from darkness, and day from night,

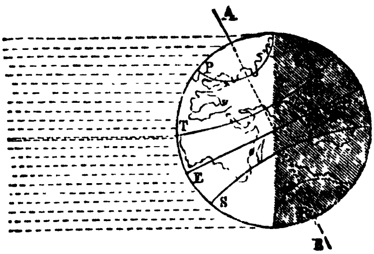


FIG. 68.

does not pass through the two poles, but is projected beyond the northern pole, and does not touch the other pole at all. Now let the terrestrial Globe turn on its axis. It is obvious that the countries between the North Pole and the circle P, which passes through the line separating light from darkness, never leaves the illuminated regions while the Globe accomplishes a rotation. For those countries which adjoin the North Pole, therefore, there is no night, and the 24 hours pass without the Sun becoming invisible for an instant. The circle P is called the Arctic Polar Circle, and it outlines the regions where, on the 21st of June, there is no more night. It is separated from the pole to the extent of $23\frac{1}{2}$ degrees, and that is exactly the amount by which the axis of the Earth is deviated from the upright position with respect to the direction of the Sun.

12. Now let us proceed a little southwards, until we reach the points which in their rotation follow the circle T, for instance. Each of these points is sometimes in the illuminated region, but they pass, in turning, into the dark region. They have, therefore, alternating day and night; but you will see at once that the passage through the dark region is shorter than the passage through the light region. Hence for such a point the night is shorter than the day. For other points describing any kind of circle not traced on the figure, but easy to imagine, day increases in length and night diminishes as they are farther advanced towards the north. On the other hand, there is an increase in the duration of the night and a diminution of that of the day as the points approach the equator E. All this is easily understood by a simple inspection of the figure. We also see that the points situated on the equator have nights

and days of equal duration—nights and days of 12 hours each ; for the portion of the equator situated in the light is exactly equal to the portion situated in the darkness.

While the northern hemisphere has days longer than nights, what happens in the southern hemisphere? The diagram shows us at once ; it shows that the days diminish and the nights increase in duration, for, on the one hand, the illuminated region becomes smaller, and on the other hand the dark region becomes larger. It also shows us that round the South Pole there is a region which rotation does not bring into light at all, and for which the Sun remains always hidden. The circle R, which limits the portion of the Earth not reached by the Sun's rays at all on 21st June, is called the Antarctic Polar Circle. That circle is also separated from its nearest pole by 23½ degrees.

13. The Sun's rays have not the same efficiency when they fall vertically down as when they fall in an oblique manner. They strongly heat the regions where they fall vertically, and only feebly heat those where they fall obliquely. In order to understand this you must have observed that to enjoy the heat of the fire to its fullest extent, we must stand straight in front of the fire, and that if we stand on one side we receive less heat. In the former case, heat falls straight down upon us and produces the maximum effect. In the second case it reaches us crosswise, and is enfeebled. In the same way, when placed in front of the Sun's fire, the Earth does not receive the same quantity of heat all over its surface, because in certain regions its rays arrive vertically, while in others they are more or less oblique. Besides this, the gain of heat by the Sun's rays in the daytime is succeeded by a loss during the night, which cools it

down. The longer the day, and the shorter the night, the hotter will the temperature be, because the gain will far exceed the loss. For these two causes combined, the temperature at some time or other is very far from being the same everywhere. It is hot at certain points, when the Sun is more or less vertical and the day is long and the night is short; it is cold where the rays are oblique, and the days are short and the nights long. Here there is winter, while in the other place there is summer.

14. Let us find the points which, on the 21st of June, receive the rays vertically, and we shall know the countries where the heat is then greatest. A vertical direction is that which when prolonged would pass through the centre of the Earth. Now it is easily seen in Fig. 68 that the Sun's rays arriving at T would pass through the centre of the Globe if they were prolonged. They are therefore vertical, so that if we stood at T we should receive them straight on our heads. It is, then, at this point that the heat is strongest. And what we have said about the point T must be said about the whole circle passing through that point, since every point of the circle will in 24 hours reach the position of noon at the point T facing the Sun. This circle is called the "tropic of Cancer," and may be defined as the circle whose points are under a vertical sun on the 21st of June at midday. It is distant from the equator by 23½ degrees, as far as the polar circles are from the nearest poles, and as far as the Earth is inclined on its axis.

In no other part of the Earth's surface are the rays vertical on that day, because in no other region do they pass through the Earth's centre if prolonged. They deviate from the vertical everywhere, and the more so

as the points are distant from the tropic, either to the north or to the south. We can verify this carefully on the diagram. The temperature, therefore, gradually diminishes on both sides of the tropic. France, lying between the tropic of Cancer and the northern polar circle at nearly equal distance from both, never has the sun vertical, but on the 21st of June the sun is nearer the vertical than at any other time of the year. And thus, at noon, we must raise our heads highest in the sky to see it.

15. Six months go by and here we have winter at the end of December. How everything is changed! In order to see the Sun at midday we must not look high in the sky, we must look lower down in front of us. And then it is so pale, and so devoid of heat! What has happened to it? Is it farther away from the Earth? Is its fire diminished? Neither one nor the other. The solar furnace does not falter or fail, but, ever active, it radiates the same amount of light and heat. Nor is it farther away. On the contrary, it is nearer, because the Earth passes at this epoch through the point in its orbit which we have called the perihelion. If it is pale and without heat it is simply due to the great obliquity of its rays and the shortness of the days. Have you noticed how short the days are? The Sun appears at 8 o'clock in the morning, and at 4 in the afternoon it has already set. That means 8 hours of day as against 16 hours of night, or the reverse of what we have in the month of June. Farther north there are nights of 18, 20, 22 hours, and days of 6, 4, or 2 hours respectively. In the neighbourhood of the pole the sun is not seen at all; there is no more day; at noon and at midnight there is the same darkness.

All this is explained if we look at Fig. 69, which represents the Earth in the position which it occupies on the 21st of December, that is when it is at the point C of its orbit (Fig. 67). The axis is still inclined, and inclined in the same direction and by the same amount. The immense journey over half its orbit has not changed its direction. But the Sun's light now arrives in the opposite direction from what it did before, because the Earth is at the other extremity of its orbit, on the other side of the Sun. There is no necessity for long explanations. We see at once that from the northern pole to the Arctic Polar Circle there is continual night; that in the northern hemisphere the days are shorter than the nights, and the more so as the country under consideration is farther north. We also see that, at the equator, day and night have preserved their equal value, that, in the southern hemisphere, the days are longer than the nights, and finally that from the Antarctic Polar Circle to the South Pole there is no more night. As regards the Sun's rays, we see that they arrive vertically at the point S, and at all points on the circle passing through S once in 24 hours, but that there is a deviation from the vertical both above and below that circle. The circle S which receives the rays of the Sun vertically on the 21st of December is called the "tropic of Capricorn." Like the previous tropic, it is $23\frac{1}{2}$ degrees away from the equator. To sum up: The 21st of June is the epoch of long days and heat for the northern hemisphere, and

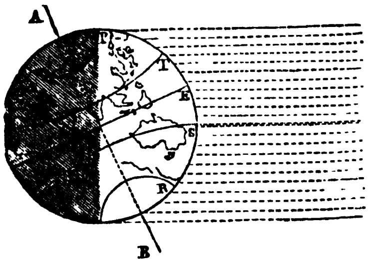


FIG. 69.

of short days and cold for the southern hemisphere. On December 21st the case is reversed. It is the epoch of long days and heat for the southern hemisphere, and cold short days for the northern hemisphere.

16. In order to proceed from the point A of its orbit to the opposite point C (Fig. 67), and to return from C to A, the Earth passes through all intermediate positions. Thus the line of demarcation between light and darkness moves gradually away from the poles or towards them, and brings about a regular increase or diminution of the duration of day and the obliquity of the Sun's rays for every point on Earth. On September 22nd the Earth reaches the point B (Fig. 67). In that position it receives solar rays vertically on the equator. The line of demarcation between light and darkness then passes exactly through the two poles, and this means that on the whole Earth the days and nights are equal and last 12 hours each. A similar thing occurs on the 20th of March, when the Earth is at the point D of its orbit (Fig. 67). The two epochs of 20th of March and 22nd of September are called the "spring equinox" and "autumn equinox" respectively. The word equinox refers to the equality which at that moment holds between night and day from pole to pole. The two epochs of the 21st of June and the 21st of December are called the "summer solstice" and the "winter solstice" respectively. The word solstice signifies that the Sun stops, meaning that after gradually rising in the sky until it becomes nearly vertical for us, the Sun stops ascending on the 21st of June and commences to retire towards the south, where it stops falling on the 21st of December in order to ascend again towards us. It is almost superfluous to say that this mounting and retreating of the Sun from one

hemisphere to another is only an appearance occasioned by the Earth and the inclination of its axis.

17. The Earth does not move with the same speed along its whole orbit. It moves fastest in winter at the perihelion, and slowest in summer at the aphelion. The seasons cannot, therefore, be of equal duration; winter must be the shortest, and summer must be the longest. Here, in fact, are the lengths of the four seasons:—

Spring	92·9 days
Summer	93·6 ,,
Autumn	89·7 ,,
Winter	89 ,,

Let us here add a table which gives the duration of the longest days from the equator to the pole, according to the latitude.

Latitude.	Hours.	Latitude.	Hours.
0 (the equator)	12	61° 19′	19
16° 44′	13	63° 23′	20
30° 48′	14	64° 50′	21
41° 24′	15	65° 48′	22
49° 2′	16	66° 21′	23
54° 31′	17	66° 32′ (polar circle) ..	24
58° 27′	18		

You may obtain the duration of the corresponding nights by subtracting the duration of day from 24 hours. From the polar circle northwards the Sun remains at least for 24 consecutive hours above the horizon, and the value of the longest day is given by the following table:—

Latitude	66° 32′ (polar circle) ..	1 day
,,	67° 23′	1 month
,,	69° 51′	2 months
,,	73° 40′	3 ,,
,,	78° 11′	4 ,,
,,	84° 5′	5 ,,
,,	90° (the pole)	6 ,,

These numbers apply to two phenomena: in the northern hemisphere to the summer solstice, and in the southern hemisphere to the winter solstice. On reversing the seasons, the same table gives the duration of the longest night.

18. As regards the distribution of solar heat, the Earth's surface is divided into five regions called "zones." The first region, called the "torrid zone," is divided into two by the equator and reaches as far as the tropics, north and south. In the torrid zone the Sun at noon is always near the zenith. Its rays arrive vertically on the ground and produce the high temperature which characterises the countries situated between the tropics. Since, on the other hand, nights and days always keep an equal length of 12 hours at the equator, and do not depart much from that equality for the rest of the zone, the cold at night is exactly compensated by the heat in the daytime, and the temperature does not vary much from one season to another. On both sides of the torrid zone there are two bands called the "temperate zones," one in the northern hemisphere and the other in the southern hemisphere. They are limited on one side by the tropics, which separate them from the torrid zone, and on the other by the polar circles which separate them from the frigid zones. The inhabitants of the temperate zones never have the Sun overhead. The Sun's rays only reach the Earth obliquely at either season, but more obliquely in the winter than in the summer. This results in a lower temperature than that of the torrid zone. Within each polar circle, right up to the poles, there are the two last zones, called the frigid zones. There the obliquity of the Sun's rays and the inequality of days and nights are greater than else-

where. In the summer the temperature rises but little, and in the winter the cold is excessive.

19. We have stated that the axis of the Earth always remains parallel to itself. But this is not strictly true. It undergoes a conical swing of extreme slowness, which results from the imperfect roundness of the Earth. A spinning top furnishes a familiar example of this oscillation of the axis. When properly thrown, it runs about on the ground and describes a sort of orbit. That movement recalls the translation of the Earth round the Sun. At the same time it swings round on its point, which corresponds to the rotation of the Earth about its axis. Finally, when it has nearly stopped, instead of remaining upright it rotates in a slanting position, and its upper end describes a more or less wide circle (Fig. 70). In the same way the Earth is subject to a conical swing about its centre. The two extremes of its axis, prolonged into the heavens, are displaced along a circle in the sky. But what majestic slowness! To describe a single one of these circles, the Earth takes 26,000 years! You may understand from this that, in spite of such an oscillatory movement, the Earth's axis may be considered parallel to itself throughout the year, without appreciable error. Yet the centuries insensibly accumulate the annual deviations, and finally warn us of the swing of the Earth by the variation of the celestial poles. We have called a star adjoining a celestial pole the pole star. At present it is the star at the end of the tail of the Small Bear. As the axis, in describing its circle

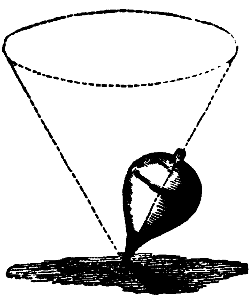


FIG. 70.

of 26,000 years meets other points in the celestial vault, the pole star will change. At the distant epoch when Egypt was building its pyramids, the pole star was the star Alpha of the Dragon. Since then the Earth's axis has gradually abandoned that constellation to pass through that of the Little Bear. For another two centuries and a half it will continue to approach the present pole star until it is only half a degree from it, after which it will move away from it in order gradually to visit other regions of the sky. In 12,000 years, the most beautiful star of our summer sky, Vega in Lyra, will have become the pole star.

SEVENTEENTH LESSON

THE CALENDAR

1. THE word "almanack" reaches us from the East and means "the moon." Time, in fact, used to be reckoned according to lunations. With its striking phases, and regular periodic returns, the Moon could not fail to serve as a first basis for the division of time. Something still remains to us of the primitive lunar calendars; this is the "month" whose length is about that of a lunation. But it is not the Moon which gives us the day and the seasons; it is not the Moon which regulates the seasons of sowing and reaping. The immense advantage of a calendar based on the movements of the Sun was perceived at an early time. The Egyptians are said to have been the first to adopt this happy thought; but, possibly on account of insufficient knowledge, they unfortunately gave their year a constant length of 365 days. Now, in order to cover its entire

orbit, the Earth requires 365 days, 5 hours, 48 minutes, and 50 seconds of mean time. The Egyptian year was, therefore, too short by about one-quarter of a day In the long run, this disagreement would have produced grave inconvenience. Let us take an outstanding epoch of the year, such as the spring equinox, and suppose that it first comes on the 21st of March. Since the year adopted is shorter than the real year by one-quarter of a day, after 4 years, when the 21st ot March returns the Earth will not yet have arrived at the equinoxal point of its orbit, but will only arrive there on the next day, the 22nd. In 8 years it will arrive there on the 23rd of March, in 12 years on the 24th, and in 16 years on the 25th. Thus, eveıy 4 years the real beginning of spring will be adjourned by 1 day in the calendar. Since this retardation occurs every year, spring will commence in turn in March, April, May, June, etc., and the seasons will gradually travel right through the year. A time will come when the cold winter will come in July and August, and the heat of summer in December and January. Harvesting will no longer be done in a definite month, nor will vintage occur in another. Hoar-frost will not cover the ground in such-and-such a month, while another month sees the fresh green. A complete discordance will establish itself between the date of the calendar and the real date of the heavens. When the former will declare for cold and the suspension of agricultural work, the latter will declare for vegetation and heat. This ancient Egyptian year of 365 days is called the Vague Year, or Wandering Year, because it makes the seasons wander from one month to another. At the end of 4 times 365, or 1,460 vague years, every day of the calendar will have passed through all the

seasons, and an agreement between the reckoning of time and the movement of the Earth will re-establish itself. But then the same deviations will recommence. The Ancients gave to this period of 1,460 vague years the name of the Sothiac period.

2. Ignorance and superstition had produced such disorder in the calendar that autumn festivals were held at Rome in the spring and harvest festivals in the middle of winter, until, 50 years before our era, Julius Cæsar undertook to put an end to this troublesome discordance. He restored to the year its true duration of 365 days and approximately a quarter. That quarter of a day was the trouble. Should it be added to the calendar year or civil year? But then, if a certain year of that calendar had commenced at midnight on the 1st of January, the next year would commence at 6 a.m., the third at noon, the fourth at 6 p.m., while the fifth year recommencing the period would bring back the commencement of midnight. With his judicious mind, Cæsar could not allow this variation in the hour of starting. He therefore left the whole number of the 365 days for the year, but he ordained that every fourth year an additional day should be added to make up for the fractions of days lost, and to restore harmony with the Sun. This reform was called the Julian Reform, from its author, Julius Cæsar.

According to the Julian Reform, three ordinary years of 365 days each come in succession, then there comes a year of 366 days, called Leap Year, or Bissextile Year. Then another period commences, also composed of three years of 365 days and a fourth year of 366. Now, of these four consecutive numbers, three are not divisible by four, but the fourth is. Hence this very simple rule

for finding leap years, or years of 366 days. If the last two figures of the year are divisible by four, the year is leap year; and in the other case it is not. Thus the years 1868, 1872, 1876, 1880, etc., were leap years, while the years 1866, 1867, 1869, etc., were ordinary years. The century years, 1800, 1900, 2000, etc., would be leap years according to this rule. But we shall soon see that, since Julius Cæsar, some of these have been exempted from the rule.

3. In arranging the calendar Julius Cæsar had to take into account the errors of the past, as well as those of the future. In order to repair the disorder already incurred, he ordained that the year in which his reforms should come into force should have 14 months and contain 445 days. That year, which, by its exceptional length, was to level up the gap of the time already elapsed and bring back the days to their true place, was called the "year of confusion." It corresponds to the year 708 from the foundation of Rome, and to the year 46 B.C. And finally, for the future, he instituted the intercalation of a supplementary day every four years, as already mentioned. For certain reasons, whose inanity would make us smile nowadays, the Romans had in their calendar an unfortunate truncated month, February, the shortest of all. Its duration was fixed at 28 days. Julius Cæsar, who did not hesitate to re-establish chronological order by prolonging the year of confusion by two months, did not dare to attack the popular prejudice and touch the 28 days of the old February. There would probably have been talk of sacrilege. And yet it is to the month of February that he added the supplementary day of leap year. Every fourth year the unfortunate month was given an

additional day, making 29, while yet preserving in appearance its 28 original days. This was done by a singular expedient.

The Romans called the commencement of each month the Calends, and it is from that word that our word calendar is derived. Now in order to indicate the end of a month they numbered the last days in relation to the calends of the next month. Thus, for instance, they called the last days of February the 6th, 5th, 4th, etc., before the calends of March. Now in the bissextile or leap years, in order to lengthen February by a day without offending tradition, which required the month to have 28 days, the expedient was adopted of doubling the sixth day before the calends, so that there was a sixth day before the calends of March as well as a second sixth day (*bis sextus*). After that doubling, February resumed its normal course, and terminated on its 28th day according to established usage. Appearances had been saved. The expression *bis sextus* has given us the name bissextile for the leap year of 366 days. Nowadays, though still truncated, as in olden times, February can at least avow its supplementary day. For three years in succession it counts 28 days, while in the fourth year it counts 29. But the word bissextile is still in evidence to remind us to what lack of common sense superstition can descend.

The Pontiffs who succeeded Cæsar were charged with watching over the chronological reform, but they made an unfortunate mistake by making leap year recur every three years. These grave personages, who predicted the destinies of the Empire by the flight of crows and the appetite of the sacred fowls, after finding grave difficulties in a month of 29 days, did not understand

that one must repeat one quarter four times to make one. The error subsisted for 36 years. Then Augustus remedied it by cancelling the leap years wrongly introduced.

4. The value adopted by Julius Cæsar for the duration of the year was too long. The Earth does not require 365 days and 6 hours to return to the same point of its orbit. It requires 365 days, 5 hours, 48 minutes, 50 seconds. The difference, amounting to about 11 minutes, gives the Julian Calendar in 128 years one day less than the real date. The first day of the 129th year has already passed by when the last day of the 128th is just finished by the calendar. To Pope Gregory XIII belongs the credit of having re-established order in the reckoning of time. At the time when his Bull was published correcting the defects of the Julian Calendar, the disagreement already amounted to 10 days. Since the dates had not progressed correctly on account of the excessive length assumed for the year, Gregory XIII decided that the 5th October, 1583, should be called the 15th of October, and that the days should be counted until the end of the year with that excess of 10 units. And then, in order to avoid such discordance in the future, due to the too-frequent recurrence of leap year, he decided that the century years, which were all leap years in the Julian Calendar, should only be leap years once in four times. That means the suppression of three days every four centuries in the old Julian Calendar. In order to carry out this suppression, the following rule is adopted. Cancel the two ciphers of the century year, and if the remaining figures form a number divisible by four, the year has 366 days, while in any other case it has 365 days. Thus the year 1600 was a leap year, and

so will be the year 2000, but the years 1700, 1800, 1900 have been ordinary years. As regards non-century years, the rule remains the same as in the Julian Calendar. The Gregorian reform did not bring about a complete agreement between the civil year and the real year, since their relation is too complicated ; but the agreement is sufficiently close to bring it about that in 10,000 years no correction exceeding 2 or 3 days is necessary. Chronology, therefore, will not have to revise the work of Gregory XIII for a long time.

The Gregorian Calendar is in use throughout the Christian world except in Greece and in Russia, where the Julian Calendar is still in force.[1]

5. The year is divided into 12 periods or months, which originate in the approximate period of a lunation. Their unequal lengths and quaint names are antiquities derived from the Romans and consecrated by usage.

January commences the series. Its name is derived from Janus, the two-faced divinity which presides over that month, and gazes with one face at the past year, and with the other at the new year.

February is said to be derived from Februo, the god of the Dead, or from the Februalia, expiatory feasts celebrated in this month. This is the month already mentioned, which is charged with bringing about an agreement of the calendar with the Sun.

March is called after Mars, the ancestor of the warlike founder of Rome, who is reputed to have given to his company of bandits an approximate calendar of 304 days divided into 10 months. Mars was the god of war from whom Romulus claimed descent. Towards the 20th or 21st of March the Earth attains the point of its

[1] This has since been remedied.—Tr.

orbit when the Sun's rays fall vertically on the equator. It is the spring equinox, when the astronomical winter ends and spring commences.

April seems to have derived its name from a Latin verb, *aperire*, to open, since that month the Earth opens, so to speak, to give rise to the new vegetation.

May derives its name from mythology, being devoted to Maia, the mother of Mercury.

June, apparently, is the disfigured name of another Roman divinity called Juno. The 21st day of that month is the epoch of the solar solstice. Then the Sun throws its rays vertically on the tropic of our hemisphere; spring is finished, and gives place to summer.

July has a more certain etymology. In memory of the happy reform brought about by Julius Cæsar in the old Roman Calendar, Mark Antony, when consul, decreed that one of the months of the year should be called Julius, the name of the reformer.

August, in Latin Augustus, bears the name of the Emperor Augustus, who repaired the error committed by the Pontiffs in connection with leap year.

The successors of Augustus, Tiberius, Claudius, Nero and Domitian made vain efforts to inscribe their ignominious names in the calendar. The remaining four months retain, as in the time of Romulus, their names of September, October, November, and December, meaning 7th, 8th, 9th and 10th. In the calendar of Romulus these denominations were rational, because the year had only 10 months, but in the Julian Calendar, which has become ours, they make nonsense. In order to retain for a month the name of December, or 10th month, when its real place is the 12th, requires all the authority of centuries, which consecrates an absurdity by mere usage.

Let us finally recall the fact that the 22nd of September is the day on which the Earth again presents its equator vertically to the rays of the Sun. This epoch is called the autumn equinox, when summer finishes and autumn begins. Finally, on the 21st of December, the Sun's rays fall vertically on the tropic of the southern hemisphere. This day, called the winter solstice, marks the end of summer and the beginning of winter.

6. The unequal value of the months is sometimes awkward. Some of them count 31 days, and others 30, while February counts 28 or 29 according to the year. How can we remember the months of 31 days and those of 30 days? A natural calendar embodied in our hands shows us very simply how to do it. Close the fist of the left hand. Where the fingers commence four knuckles stand out, separated by hollows. Place the index finger of the right hand on to the knuckles and hollows in turn, starting from the finger nearest the thumb, and call out the names of the months, January, February, March, etc. When the series of the four fingers is finished, go back to the first finger and start again with the remaining ones. Then any month which falls on a knuckle has 31 days, and those which fall in the hollows have 30 days, except February, which falls in the first hollow and has 29 days in leap years and 28 in ordinary years.

7. The months are divided into weeks. The ordinary year contains 52 weeks and one day. On account of its antiquity the calendar has retained the memory of the past of the human race in its minor details. Pagan superstitions are inscribed on most of the names of the days of the week. Paganism had, in fact, consecrated each day of the week to one of the divinities adored in the name of heavenly bodies. We have inherited the

denominations used in such star-worship. Thus Monday signifies Moon day, and Sunday signifies the day sacred to the Sun. Saturday is the day of Saturn. Tuesday, Wednesday, Thursday, and Friday are names after ancient Teutonic deities: Tiu, the god of war; Wotan, the god of the heavens; Thor, the god of thunder; and Freya, the goddess of spring.[1]

8. The epochs of our religious festivals are determined by the calendar. Some of the festivals are fixed, while others are movable. The former are celebrated on an invariable date, among them being Christmas, which comes on the 25th of December every year. Others are celebrated year after year at different times according to the combined movements of the Sun and Moon. The most remarkable of these is Easter, which regulates the other movable feasts. The Resurrection of our Saviour having closely followed the spring equinox and a full Moon, it seemed right to the Church to be guided by this double astronomical fact, and Easter was fixed on the first Sunday following the first full Moon of the spring equinox. From these multiple conditions, Sunday, full Moon, and vernal equinox, each requiring a certain wideness of limits to be realised separately, it results that Easter is celebrated on dates which can vary from 22nd of March to the 25th of April; including both dates there are 35 days. And thus Easter may, as the years go by, fall on 35 different dates.

Once Easter is determined, the other movable feasts such as Ascensiontide, Whitsuntide, etc., are also fixed, for Ascension is celebrated on the 40th day after Easter,

[1] The French names are derived as follows: Mardi from Mars, Mercredi from Mercury, Jeudi from Jove or Jupiter, Vendredi from Venus, while Dimanche is from *dies dominica*, the Day of the Lord.

and Whitsuntide on the 50th day.[1] It is clear that these feasts, separated from Easter by a fixed number of days, must also alter in date within the limits of 35 days.

9. The natural date for the departing year should be some remarkable astronomical epoch, such as a solstice or an equinox. But usage, which does not always consult reason, has decided otherwise. For us the year commences on the 1st of January. This convention is, however, fairly recent, having been prescribed in France in 1563 by an edict of Charles IX. In the times of Charlemagne, the usage was to commence the year at Christmas, while in the twelfth and thirteenth centuries the first day of the year was Easter itself.

The word epoch is used for the year from which chronology is reckoned. In their chronology, the Romans reckoned from the foundation of Rome, which was about 753 B.C. We must therefore add 753 of our years in order to refer them to the foundation of Rome. In the Christian world chronology is based upon the supposed date of the birth of Jesus Christ, and is called the Christian epoch. The epoch of the Mohammedans is called the Hegira, which corresponds to the year 622 A.D. The word Hegira means flight, and refers to the flight of Mohammed from Mecca to Medina. The lunar calendar of the Mohammedans, which alternately comprises lunations of 29 and 30 days, does not allow us, without very complicated calculations, to translate our dates into dates based upon the Hegira.

[1] This reckoning includes the original Easter Sunday.—TR.

EIGHTEENTH LESSON

THE SOLAR SYSTEM

Planets and satellites, 1.—Origin of the word planet, 1.—The fixed stars, 1.—Planetary arrangement, 2.—Distances of the planets, 3.—The chariot which carries us along at the rate of 68,000 miles an hour, 3.—The greatest geometrical base, 3.—Bode's Law, 4.—The distance of Neptune and the anvil of Hesiod, 5.—Volumes of the planets, 6.—Supremacy of the Sun over its guard of planets, 6.—Image of the solar system, 7.—The grindstone and the grain of hempseed, 7.—How planets accompanied by satellites are weighed, 8.—Total weight of the planets compared with the Sun, 8.—Density of the planets, 9.—The globes which float on water, 9.—The year and the day of the planets, 10.

1. AROUND the giant of the heavens, the Sun, which by its attraction keeps them in perpetual orbits, there are various globes circling in company with the Earth Some of them are larger and some of them are smaller than the Earth ; some of them are far away and some are near. All are dark by themselves, and, like the Earth, they receive from the Sun their ration of light and heat. They are called planets. And while the secondary stars proceed round the royal star, some smaller globes of less importance revolve round some of them as the Moon does round the Earth. These smaller bodies are called satellites. The Sun, with its retinue of planets and satellites, constitutes what is known as the " solar system."

The word planet signifies something which roams, Indeed, while the stars preserve their invariable positions

with respect to each other, as if they were fixed to a solid vault which moved in one piece, the planets, on account of their voyage round the Sun, are disposed to roam, so to speak, about the firmament, reaching different regions of the starry sky as seen from our point of view. One day a certain planet will be found in a certain constellation, to-morrow it will be taken into another constellation by its proper motion. The planets may be recognised by their roaming among the other stars, which we may call fixed stars.

The word satellite calls attention to the subordinate part played by these smaller bodies. It means a guard or servant, and signifies that the smaller body is the servant of the one it accompanies. It reflects sunlight to it, and receives in return sunlight reflected by the planet itself. We can fix this definition by saying that the Earth is a planet and the Moon its satellite.

2. The planets now known to astronomers number several hundred. Here are their names in order of their distance from the Sun :—

Mercury.	Jupiter.
Venus.	Saturn.
The Earth.	Uranus.
Mars.	Neptune.
The Asteroids.	

Like the Earth, each planet describes round the dominating star an ellipse which differs but little from a circle, and all these elliptic orbits have a common focus occupied by the Sun. But the other foci change from one planet to another, and the widths of the ellipses change also so that the various planetary orbits can never cross or interpenetrate each other except in the case of the asteroids. Their orbits also lie in all sorts

of directions, as compared with the Earth's orbit. Some of them rise away from it, others descend or lean to the right or left, but all are approximately contained in the same plane, like concentric circles traced on a sheet of paper, and this common plane is nearly identical with the extension of the Sun's equator. The sense of the circulation of the planets round the Sun is the same for all. I have told you that a spectator placed in the axis of the Sun with his head placed towards the North Pole would see this star turn from his right to his left. It is in the same direction that he would see the planets circling round the Sun, and it is in the same direction that they themselves would turn, and in the same direction still that the satellites would turn round their respective planets.

3. The first question to settle with regard to the planets is that of their distance. Here a difficulty presents itself similar to that presented by the excessive distance of the Sun. The Earth is too small to furnish the necessary base for such measurements. Astronomers, however, got round the difficulty by a very happy expedient. What is essentially necessary to find the distance of an inaccessible object? A base of suitable length, and two angles. Now, since we cannot obtain on the Earth a base of sufficient length, even from pole to pole, we must use the chariot which hour by hour takes us 20,000 leagues farther. We must use the translation of the Earth. At the present moment we occupy a certain position in space. In an hour, two hours, or three hours, we shall have left this point once, twice, or three times 68,000 miles behind. That certainly gives us a wonderful base. It grows into enormous proportions, and we travel along it without leaving our study. To-day

the astronomer on the terrace of his observatory makes one observation of the planet he is studying. That observation gives him a first angle. Next day at the same hour another observation gives him the second angle. As regards the base of the triangle, it is 24 times 68,000 miles, and it is the Earth's business to traverse it and to measure it. And if, in spite of its length, amounting to 200 times the diameter of the Earth, the base is not yet sufficiently long, what prevents us from waiting a few days? By waiting six months the astronomer would make his first observation at one end of the diameter of the terrestrial orbit and the second at the other end. The base would then be double the distance separating us from the Sun, that is, 186 million miles. It is on that immense line that Geometry erects its triangles when it wants to sound the heavens. But for the planets no such lengths are necessary. A few days suffice to enable the Earth to cover a distance comparable to the distances of the planets.

It is by following this method, of which I have given a general outline without the details, that Astronomy has succeeded in measuring the distances of the various planets from the Earth, and hence also from the Sun. Without loading our memory with the numbers thus obtained, a mnemonic rule of great simplicity enables us to find the series of the planetary distances. Put down zero and then 3. Then double this number, and continue by always doubling the result. You will get the series :—

0 3 6 12 24 48 96 192 384

Now add 4 to each term of that series and you will obtain the following numbers :—

4 7 10 16 28 52 100 196 388

Finally write these numbers in order against the list of the planets arranged in order of their distance from the Sun :—

Mercury	4	Jupiter	52
Venus	7	Saturn	100
The Earth	10	Uranus	196
Mars	16	Neptune	388
The Asteroids	28		

This table tells us that if the distance between Earth and Sun is represented by 10, the distance between Venus and the Sun will be 7, the distance of Mars 16, and that of Saturn 100, etc. If you wish to convert these relative values into miles, you must remember that the distance between Earth and Sun is 93 million miles. According to this the distance of Jupiter, for instance, is 52 times one-tenth of 93 million, or 486 million miles.

4. This rule is known by the name of "Bode's Law." The word law is not appropriate here, since it seems to designate a numerical ratio really applying to planetary distances, whereas it is only an ingenious combination suitable for assisting the memory. In using this so-called law we must not forget that it only gives approximations, which, however, suffice for us. Thus, according to Bode's Law the distance of Jupiter from the Sun would be 493 million miles, instead of its real distance, 483 million miles. The number 28 for the group of the asteroids is a mean value for all the distances of the small planets making up this numerous group. Finally, the last term is at fault. If the Earth's distance is 10, Neptune's distance is not 388, but only 300.

5. Let us deal for a moment with this last distance. Neptune is placed on the confines of our solar system. It is the most distant of the planets illuminated by the

Sun. In its immense orbit it encloses the orbits of all the other planets. In order to measure its distance we should have to place the 93 million miles separating ourselves from the Sun end to end 30 times. Would that be the extreme limit of the Universe? No. For beyond that, at distances in comparison with which it is a mere nothing, innumerable legions of other suns are shining, each of which is probably the centre of a planetary system such as ours. These are the stars. The orbit of Neptune, therefore, only embraces a little corner of the sky, a mere point, and yet our imagination is unable to figure its formidable dimensions. A famous poet of antiquity, Hesiod, wishing to give a correct idea of the Universe as he conceived it, could think of nothing better than the following image. If, he said, a great anvil were left to fall from the top of the celestial vault, it would take 10 days to reach the Earth. How small is the sky of poetry in comparison with the sky revealed by science! Let us ask ourselves what time would be required by Hesiod's anvil to descend from Neptune to the Sun. We find by calculation that it would take 30 years! Just compare the two falls, and do not forget that our own takes place in a small corner of the heavens.

6. From the distance of the planets and their apparent diameter, their volume is easily deduced by the method which I have already mentioned. The following table contains the volumes of the different planets, that of the Earth being taken as the unit:—

Mercury	$\frac{1}{17}$	Jupiter	1,414
Venus	1	Saturn	734
Earth	1	Uranus	82
Mars	$\frac{1}{7}$	Neptune	100
Asteroids (max.)	$\frac{1}{2000}$		

You will see that there is a great variety in the respective sizes of the Earth's companion planets. There are miniature globes, pigmy planets, of which we should have to take 2,000 to reach the volume of the Earth. These are the asteroids. Mercury is also very small. If the Earth were hollow, it would take 17 Mercuries to fill it up. Then comes Mars, two or three times larger than Mercury; then Venus, nearly equal to the Earth. So far, the supremacy as to volume is in our favour, but then come the giants of the planetary family, especially Jupiter, which represents 1,414 globes like ours combined into one. A small cherry, compared with a large orange, gives us the relation between the Earth and Jupiter.

When we think of these colossal globes—Uranus, Neptune, Saturn, and Jupiter—before which our humble Earth is almost effaced, we must ask ourselves how they can be mastered by the Sun which from the focus of their orbits retains them in their constant paths by its attraction. Do not the planets greatly surpass in their aggregate mass the dominating star? Cannot the retinue of planets compete with the Sun in energy? A very simple calculation shows that they cannot. Let us add the numbers of the last table together. They will, together, not reach 2,400, even including the satellites which are not in the above table. Thus, taking the terrestrial Globe as a unit, the combined volumes of all the planets and their satellites do not reach 2,400, while the volume of the Sun, as you will remember, is 1,400,000. The Sun alone, therefore, is 600 times more voluminous than the whole family of planets. It could comprise within its ball the whole assembly of planets and satellites, not only once, but 600 times. It is the

master, there is no doubt; never will Saturn, and never will Jupiter escape from its bondage.

7. In order to conceive in its entirety the solar system, and appreciate the relation between the distances and volumes, let us imagine the following arrangement. In the middle of a great and perfectly level plain we place a ball 4½ feet high. That sphere, which is nearly as large as a millstone, represents the Sun. In order to represent Mercury we should have to place a small hemp-seed at a distance of 58 feet away from the great ball. Venus and the Earth would be represented by two small cherries, placed, the former at 276 feet and the latter at 400 feet from the ball. A small pea would suffice for Mars, the planet of war, placed at 600 feet from the great ball. The group of the asteroids would be represented by a pinch of fine sand disseminated here and there on a circle with an average radius of 1,100 feet. The great planet Jupiter would be represented by a very large orange placed at a distance of 2,500 feet, and Saturn at 4,000 feet by an ordinary orange. Uranus would be nearly 1¼ miles away, and would be shown by an apricot, and finally, Neptune, about 2½ miles away, would be of the size of a peach. By the side of the Earth, Jupiter, Saturn, Uranus, and Neptune, imagine one or more small lead shots to represent the satellites of the planets, and then imagine that the whole of these travelled round in unequal times round the great ball of stone, and you will have a very faithful representation of the solar system. Is it necessary to go further to make you understand how small are the planets—the peach, orange, cherry, hempseed—in comparison with the Sun?

8. The mass of a planet accompanied by satellites is

determined by the method which has already been used to weigh the Sun. We calculate from its movement how much a satellite falls in one second towards its planet, as we already did in the case of our Moon, and the result obtained is compared with the ordinary fall of terrestrial bodies. If, for the same distance, the satellite descends towards its planet two or three times more quickly than bodies fall towards the Earth, that means that the planet contains two or three times more matter than the terrestrial Globe. Even in the absence of satellites, the planet may be weighed, but it is then an arduous operation with which we cannot deal here.

The respective masses of the planets are contained in the following table, the Earth being the unit :—

Mercury	$\frac{1}{13}$	Jupiter	338
Venus	$\frac{9}{10}$	Saturn	101
Earth	1	Uranus	15
Mars	$\frac{1}{8}$	Neptune	21

As regards the small planets situated between Mars and Jupiter, it is known that their masses are very small, though their precise amount is unknown.

The predominance of the Sun over the aggregate of the planets and their satellites with regard to volume also applies to weight. If the above numbers are added up, we shall not get 500 for the total weight, even including the satellites. On the other hand, we have seen already that the Sun weighs as much as 354,936 globes similar to the Earth. Thus, if it were possible to place it in the pan of a balance, we should require at least 700 times the total of the planets to counterbalance the Sun.

9. The comparison of planetary volumes and weights leads to curious results. Jupiter, for instance, which is 1,414 times larger than the Earth, only weighs 338 times

more. Mercury, on the other hand, though 17 times less than the Earth, only weighs 13 times less. It follows that the matter comprising Jupiter is less heavy, for an equal volume, than that of the Earth, while the matter of Mercury is heavier. These differences are more easily understood in the following way. Let us suppose, as we have already supposed in the case of the Earth in another chapter, that the whole matter of each planet is intimately mixed up, and let us take the weight of a gallon of the mixture. We shall obtain the following table :—

Mercury	49 lbs.	Jupiter	14 lbs.
Venus	52 lbs.	Saturn	6 lbs.
Earth	55 lbs.	Uranus	13 lbs.
Mars	39 lbs.	Neptune	13 lbs.

Thus Mercury, the Earth, and Venus are nearly similar in density; Mars is lighter in comparison, while the other planets are much lighter. Saturn does not even reach the specific gravity of water, so that it would float on water like a sphere of pine.

10. In order to describe its orbit round the Sun each planet requires a different period, which is longer the greater its distance from the central body. That period constitutes the year of that planet. In taking our day and our year as terms of comparison, we find, for the years of various planets, the following values :—

Mercury	88 days	Jupiter	12 years
Venus	225 ,,	Saturn	29 ,,
Earth	1 year	Uranus	84 ,,
Mars	2 years	Neptune	165 ,,
Asteroids (mean) .	5 ,,		

These values, which we express for the sake of simplicity in round numbers, show us the great variety there is

between the durations of revolution round the Sun for the various planets, that is, in the length of their year. While Mercury completes its voyage in 88 days, which gives it seasons shorter than a single one of our months, and lasting only 22 days, Neptune, on the outskirts of the solar system, takes 165 years to complete its orbit, so that its year equals 165 of our years, and each of its springs or winters lasts 41 years.

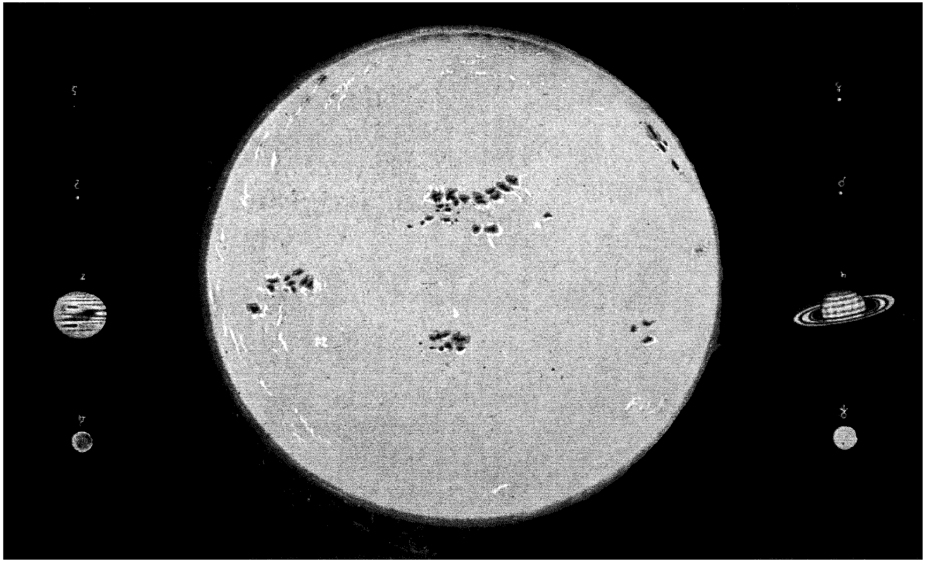
The rotation about the axis which, as in the case of the Earth, produces alternating day and night, is nearly 24 hours for Mercury, Venus, and Mars. On these planets the days and nights are, therefore, much like our own. Jupiter, in spite of its enormous volume, is much more rapid. In 10 hours it exposes all its sides in turn to the rays of the Sun, so that each of its hemispheres is illuminated for 5 hours, and plunged into darkness for 5 hours. Saturn rivals Jupiter in rapidity, turning on its axis in 10½ hours. For Uranus and Neptune the duration of rotation is still unknown on account of the excessive distance of these planets

NINETEENTH LESSON

THE PLANETS

Classification of the planets, 1.—Interior planets and their phases, 2. —Exterior planets without phases, 3.—Mercury. The Sun seen from Mercury. The planet's atmosphere, 4.—The seasons of Mercury, its mountains and its volcanoes in eruption, 5.—Venus, the Shepherds' Star ; its mountains, its atmosphere and its twilight, 6.—Influence of the obliquity of the axis on the seasons, 7. —The seasons of Venus, 7 and 8.—A false step of the Earth would change conditions of life, 8.—Stability of the Earth's axis, 8. —Mars ; its aspect, its continents and seas, 9.—The brilliant patches of the poles, 10.—The polar snows of the Earth seen from space, 10.—The polar snows of Mars, 11.—Sun seen from Mars, 12.—The illuminated atmosphere of the planet, 12.—The planet which most closely resembles the Earth, 12.

1. ACCORDING to their position in the solar system, the planets are divided into two groups, one of which is called the group of the interior or inferior planets, and the other the exterior or superior planets. The former comprises Mercury and Venus. They are called interior because their orbits are enveloped by that of the Earth, and inferior because they are closer to the Sun than we are, though they all gravitate round the latter as terrestrial bodies gravitate about the centre of the Earth. From this point of view, the Sun is the lowest in the solar system, just as the Earth's centre is the lowest point in our Globe, whereas the mass of the planet Neptune, or any planet still farther away, constitutes its highest. The planets of the second group—Mars, the asteroids,



M. THE SUN AND THE PLANETS.

☿ Mercury. ♀ Venus. ♁ Earth. ☾ Moon. ♂ Mars.
♃ Jupiter. ♄ Saturn. ♅ Uranus. ♆ Neptune.

To face p. 252.

Jupiter, Saturn, Uranus, Neptune—are called exterior because their orbits encircle that of the Earth, and superior on account of their position farther from the Sun than ourselves, and therefore higher up.

To this classification we may add another, which envisages the planets from a more general aspect. Three groups may be distinguished. The first, comprising Mercury, Venus, the Earth, and Mars, is formed of globes of average size, only slightly flattened at the poles and consisting of heavy matter. They are, with the exception of the Earth and Mars, without satellites. The second group comprises the asteroids, which are remarkable for their number, their small volume, their feeble mass, and their orbits, which interlace and stray considerably from the common plane which contains the orbits of the other planets. Jupiter, Saturn, Uranus, and Neptune comprise the third group—the group of giants. Here the volume is enormous, while the density is feeble; the poles flatten considerably, and the satellites are numerous. Jupiter has 5,[1] Saturn 8,[1] together with a satellite in the form of a ring, Uranus 8, and Neptune 1.

2. The distinction of planets as exterior and interior is essential. The interior planets present phases similar to those of the Moon, meaning that according to the epoch of observation they are seen full or partly, or not at all, since they turn either the whole or a portion of their illuminated hemisphere, or their dark hemisphere towards us. The exterior planets, on the other hand, always appear full, with the exception of Mars, which occasionally wanes slightly at the edge. These differences of aspect between the two groups of planets are

[1] Some smaller satellites have recently been discovered by photo graphic means.—Tr.

due to the position occupied by the Earth, a position which sometimes puts us face to face with the dark hemisphere of the interior planets, but always leaves us facing the bright hemisphere of the exterior planets. Let us seek the help of a diagram.

Let S be the Sun (Fig. 71), V an interior planet such as Venus, T the Earth, and M an exterior planet such as Mars. At the time when the Earth is at T in its orbit,

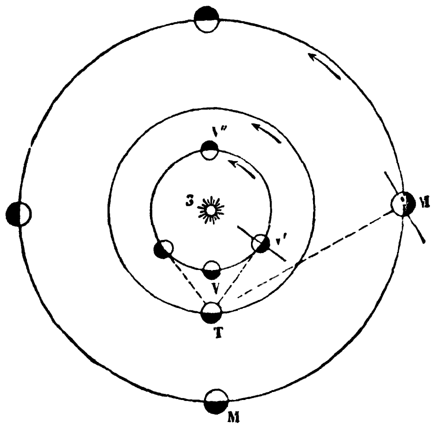


FIG. 71.

the interior planet V may occupy one point or another in its own orbit. When it is at V, between us and the Sun, it turns towards us its dark hemisphere, and is therefore invisible. That phase corresponds to that which we have called the new Moon in speaking of our own satellite. If it were placed exactly on the line joining the Earth to the Sun, we should see the interior planet passing like a small black point across the radiant disk of the Sun. That would be a " transit of Venus." As it progresses on its orbit, it shows us gradually a

portion of its illuminated hemisphere in the shape of a crescent, and when it reaches V′ it shows us just half. The phase thus presented is that of the last quarter of the Moon. Finally, arriving at V″ opposite the Sun, the planet has the aspect of a complete disk because it turns its whole illuminated hemisphere towards us. I need not say that if it would pass exactly in a straight line behind the Sun it would be hidden by the Sun's enormous disk, but that occurs very rarely. Usually the planet passes a little above or a little below a straight line, joining the Sun and the Earth. This is due to a feeble inclination of its orbit with respect to that of the Earth. Beyond V″, the planet's disk wanes, becomes a crescent, and finally disappears.

3. The case is very different with the exterior planets. In the first place, an observer placed on the Sun, which is the centre of planetary illumination, would see, of course, the illuminated hemispheres of all the planets at once, but for the extreme brightness which would surround him and would prevent him from seeing bodies of such small luminosity. In other words, for him the planets would always be "full." Something like this happens to us with regard to the exterior planets, especially the more distant ones. We do not look upon them from the centre of the solar system, but from a point near the centre, the Earth being very near the Sun in comparison with the great distances of other planets. On account of our nearly central position, Jupiter, Saturn, Neptune, etc., always turn towards us their hemisphere facing the Sun. A glance at the diagram suffices to show that in traversing its orbit the exterior planet M turns its illuminated half towards the Earth. This is the more exact the farther the planet considered is distant from

the centre of the system. Mars, which is a fairly close neighbour, at some epochs shows us a small portion of its dark hemisphere, in spite of its rank as an exterior planet, and its disk thus appears slightly deformed. But it never becomes a crescent, and never becomes entirely obscure. We see at M′ the position which Mars occupies when it presents to the Earth a little cut of its dark hemisphere.

4. Mercury, the first of the interior planets, is rarely visible to the naked eye, being too close to the Sun, around which it describes its narrow orbit. It appears like a small star with vivid, twinkling light, sometimes a little after sunset, sometimes a little before sunrise, so that we cannot see it without instruments except low on the horizon amidst the glow of twilight or dawn. Its phases are as well defined as those of the Moon. One day it will show as a thin crescent, the horns of which are turned away from the Sun on account of its illumination by the latter; another day it will take the form of a half-disk, and again a disk almost complete. A telescope is absolutely necessary to see these different aspects of the planets. Mercury is about 2½ times closer to the Sun than the Earth. The Sun must therefore be 2½ times larger than it is seen from the Earth, and its apparent disk must be 6 or 7 times larger. Imagine seven Suns like ours sending their rays on our heads, and you will have the exact measure of the effect produced on Mercury by the Sun. Illumination is 7 times brighter there and heat is 7 times greater. But possibly the atmosphere, which astronomical observations agree in finding around Mercury, modifies this torrid temperature and this blinding clearness. We all know how the interposition of a thick curtain of clouds reduces for us

the rays of the Sun. Now the atmosphere of Mercury is apparently very cloudy, for we often observe on the luminous disk of the planet the sudden formation of dark bands occupying considerable space, and presenting very sensible variations of brilliance.

5. In any case, Mercury must, nevertheless, be under conditions of excessive heat and light, and must have seasons of which we on Earth can form no idea. In 88 days Mercury revolves round the Sun. That constitutes its year. Every season therefore contains only 22 days. Besides, the axis of the planet is so much inclined to the plane of the orbit that the Sun is in turn very near one pole or the other, so that there are no temperate zones. For 44 days an immense zone, of which the planet's North Pole is the centre, sees the Sun passing round the horizon without ever setting, while the opposite zone centring round the South Pole is plunged in perpetual darkness. The situation is reversed in the second half of the year, which lasts 44 days: the southern zone has continual light and heat, while the northern zone has night and cold. Only the equatorial belt has all the year round during the 24 hours and 5 minutes taken by the rotation of the planet a regular return of day and night, of heat and cold.

From the jagged aspect of the crescent of Mercury we may draw the conclusion that the planet possesses mountains. It has been found possible to measure one of them. Its height is about 12½ miles, an enormous height in proportion to the dimensions of the planet. The Earth, 17 times more bulky, has nothing to compare with it, since its highest mountain is only about 6 miles high. Finally, a small luminous point perceived by various observers on the black disk of Mercury during

one of its transits across the Sun leads us to believe that the little planet possesses active volcanoes.

6. Venus is that magnificent star [1] which sheds a vivid white light before sunrise and after sunset. It is often seen even in daylight, it is so brilliant. When it appears in the east it is often commonly called the morning star, and it is also called the evening star when in the west. The ancients called it Lucifer in the morning and Vesper in the evening. It is also called the shepherd's star. These various names show how at all times the brilliant planet has impressed even the most inattentive observers. The phases of Venus are admirably clear, yet the naked eye does not suffice for their observation. It is a crescent when it is nearly between us and the Sun in a position near V′ (Fig. 71). It is then that it shines with the greatest brightness and the greatest size, though only a portion of its disk is visible. When it reaches V″, opposite the Sun (Fig. 71), it turns its whole illuminated hemisphere towards us, yet it appears smaller and less brilliant since it is at a much greater distance. At V Venus is 24,400,000 miles away from us; at V″ it is 16,200,000 miles away.

Astronomers agree in recognising on Venus mountains of such a height that we can scarcely believe it. It is said that some of them are 27 miles high. Our Cordilleras and our Alps, whose white summits plunge into the clouds, are only hillocks in comparison with these Venus peaks 11 leagues high. Finally, the twilight which extends beyond the portion of the disk directly illuminated by the Sun proves the existence of an atmosphere on Venus corresponding to our own.

[1] The word star is not quite appropriate here, since it designates heavenly bodies shining by their own light and not the planets which only borrow their light from the Sun.

7. In one of the lessons dealing with the Earth you have seen how the inclination of the axis of our Globe with respect to the plane of its orbit produces the seasons and inequality of days. If that inclination were greater the seasons would entirely change their character, and so would the alternation of day and night. Mercury, whose inclination is much greater, gives us one example of this, while Venus furnishes another, and this I shall discuss in greater detail.

The axis of this planet makes an angle of 18 degrees

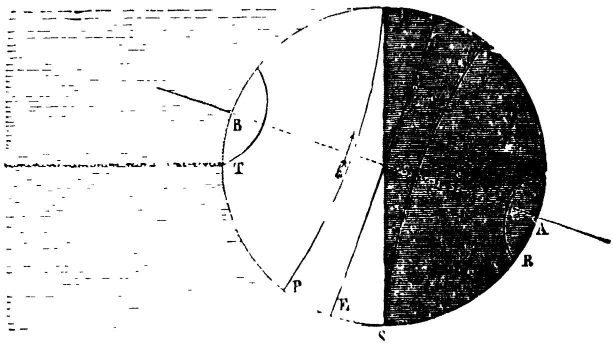
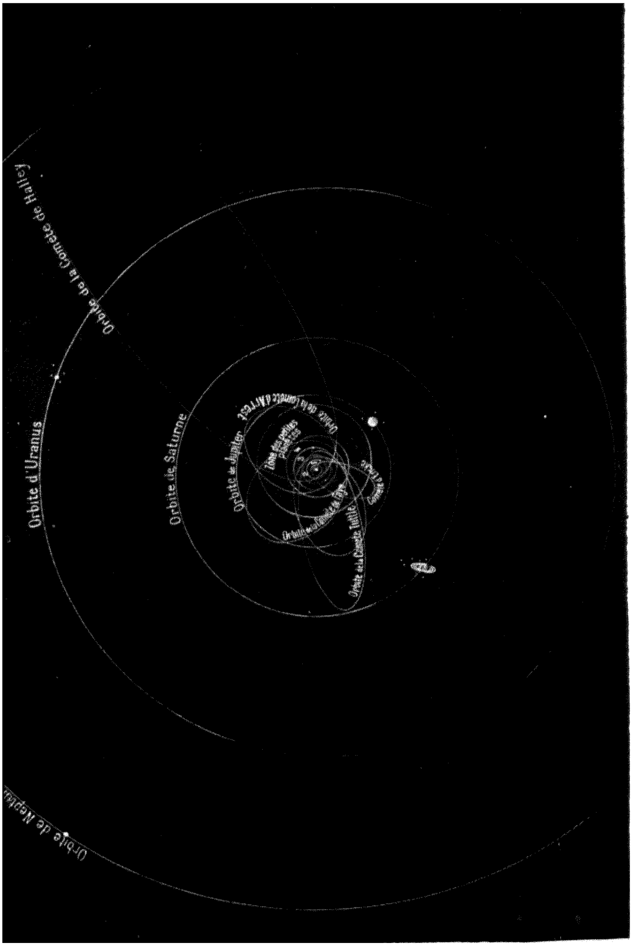


FIG. 72.

with the plane of its orbit, while the Earth makes an angle of 67 degrees. Compare Fig. 72, representing Venus at the time of its summer solstice, with Fig. 69, concerning the Earth, and you will see how much the two planets differ in their manner of presenting themselves to the rays of the Sun. In order to understand the principal consequences of this great inclination of the axis of Venus, let us in our minds make the globe in Fig. 72 turn round its axis AB in the direction of the arrow. It is obvious that the points describing the parallel P do not leave the illuminated region during the

23 hours and 21 minutes taken by the planet to complete a rotation. Thus, from the North Pole B as far as the parallel P the Sun does not set, and there is no night. In employing the terms already applied to the Earth we shall call this parallel P the northern Arctic circle of Venus, since it limits the regions where there is no night on Venus during the summer solstice. We also see that the Sun's rays arrive vertically on the parallel T near the pole. Hence that parallel is the northern tropic of the planet. There is, therefore, a reversal of the polar and tropic circles on Venus as compared with the Earth. Our tropics are near the equator, and our polar circles are near the poles, while on Venus the polar circles are near the equator and the tropics near the poles. This reversal produces the most extraordinary differences between our seasons and those on Venus. The northern regions of the Earth have, indeed, long days during the summer solstice, days without night, but the Sun has no strength there on account of the obliquity of its rays. The northern regions of Venus have at that time perpetual day combined with a vertical Sun, which is twice as hot and twice as bright as ours on account of its smaller distance. The combination of these conditions must produce a more extreme climate than that of our equatorial countries.

8. While the northern zone of the planet is under the influence of a permanently blazing Sun, the southern zone, from the pole A to the polar circle S, is plunged into perpetual darkness. The temperature, therefore, must fall until it becomes comparable, no doubt, with that of our polar regions in the winter. Only the narrow belt between the two polar circles, P and S, which is bisected by the equator E, has at that time alternately



N. THE SOLAR SYSTEM, SHOWING ORBITS OF PLANETS AND THE CHIEF COMETS.

[To face p. 260.

day and night. Everywhere else there is perpetual day or perpetual night, excessive heat or excessive cold.

But the planet revolves in its orbit. Little by little the Sun's rays cease to arrive vertically on the tropic T, and fall on a lower parallel. The equator is reached at the moment of the equinox. Finally, in less than four months, a half of the orbit is covered, a half of the year has elapsed,[1] and the Sun projects its vertical rays on the second tropic R. We will suppose in Fig. 72 that the Sun's rays, instead of coming from the left, come from the right, on account of the situation of the planet at the other end of its orbit, and you will easily understand the coming of the long days and the heat in the southern regions of Venus, and the coming of long nights and cold in the northern regions.

To sum up, the strong inclination of the axis of Venus brings it about that it has no temperate zone. An extreme climate, torrid and glacial in turn, passes from one pole to the other every four months. If such a thing happened to the Earth, there would be an end of animal and vegetable species, organised for their special climates. On the coming of the darkness and hoar-frosts from the poles, the chilly species of the equator would perish; while under the vertical rays of an implacable Sun the polar species would also perish. The population of the Earth is, therefore, in close dependence upon the inclination of its axis. A false move on the way made by our rushing Globe, which covers 6,700 miles in each hour, would upset the conditions of life by altering the axis and thus changing the seasons. But this *faux pas* is not likely to occur. The supreme Finger which touched the pole and inclined the Earth before the Sun in order

[1] The year on Venus is equivalent to 224 of our days.

to produce its climates, has for ever stabilised its axis to an extent in harmony with its organised beings.

9. According to the order of distance from the Sun, the Earth is next to Venus. But as we have already dealt with the Earth elsewhere, let us pass it by and come to Mars, the first of the exterior planets. Mars appears to us as a brilliant star noticeable among all the others by its vivid red colour. It completes its orbit in 687 of our terrestrial days, which is about 1 year and 10 months. When it is on the same side of the Sun as the Earth, it is only 35 million miles away; but when it reaches the opposite point of its orbit, its distance is 265 million miles. Its apparent size and brightness are therefore different at different times. When examined in the telescope, especially when nearest the Earth, Mars presents to us one of the most curious spectacles in the skies. Its disk is studded with great spots of permanent shape and exquisitely clear outlines, some of which are reddish, while others are of an undecided green. One has the impression of looking at the hemisphere of a little map of the world, in which the continents are coloured red and the oceans green. That would be approximately the appearance of the Earth if we were to see it from some neighbouring planet. It has been supposed that the red patches correspond to continents, the greenish patches to seas. These patches appear first on the western edge of the planet, and pass gradually under the eyes of the observer towards the eastern edge, to reappear eventually at the other edge. The time between the two consecutive returns of the same spot at one edge or another is 24 hours and 37 minutes. Mars, therefore, turns on its axis once in 24 hours 37 minutes. This is a new point of resemblance with the

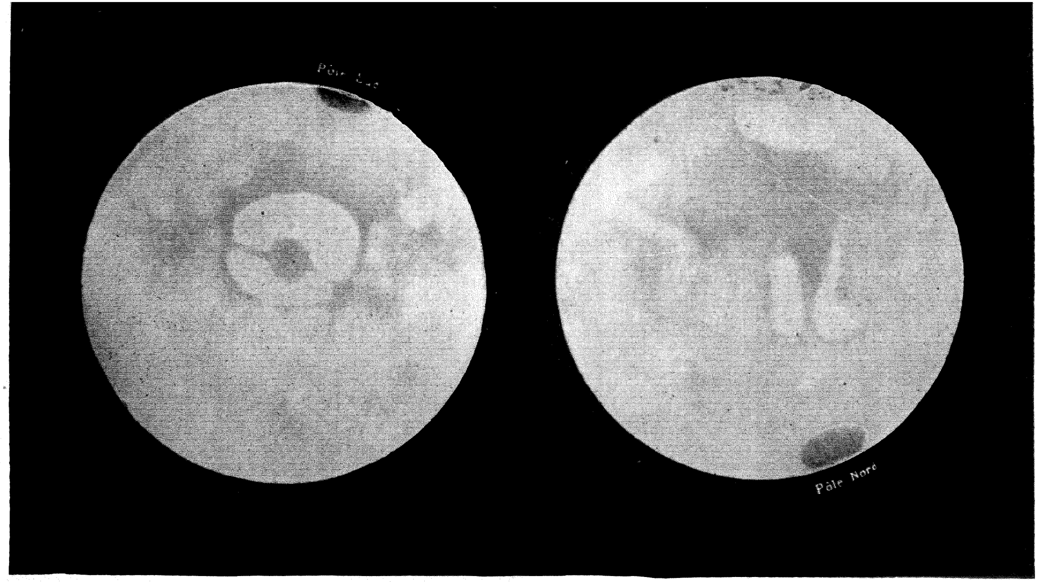
Earth, which takes 24 hours to accomplish its daily rotation.

10. Besides the patches mentioned, a circular spot of a vivid white occupies each of the poles of the planet, and stands out clearly from the reddish or greenish tints suggesting continents or seas. The size of these polar patches is periodically variable. During one-half of the Martian year, corresponding to the hot season of the northern hemisphere, the northern patch becomes gradually smaller and recedes towards the pole before the advancing Sun. At the same time, the southern patch, which is then in the middle of winter, enlarges its dimensions, and projects over the red and green patches. In the second half of the year of that planet the seasons are reversed: the southern hemisphere having summer, and the northern hemisphere winter. Then the northern white patch becomes larger, while the southern one is diminished. What can be the significance of this white mantle of the two poles, which extends or contracts as the Sun abandons it or comes back to it? For an observer looking at our Globe from some point of the heavens, the Earth would present absolutely the same appearance at its poles. An immense dome of snow and ice, which never entirely melts, occupies the Arctic extremity of the Earth, a similar dome, of somewhat greater extent on account of its more rigorous winter, covers the southern extremity. Seen from space, these two domes of snow must appear like round patches of blinding white colour, which every six months become larger or smaller according to the seasons. At the present moment, I suppose, up there in the north, the mantle of winter snow shines in its whole extension. Hoar-frost passes beyond the Arctic zone and penetrates even into the temperate zone. In the south, the ice floes

are melting, the frozen seas become free, the snow disappears, and the warm soil smiles at the Sun which brings back vegetation. Six months later it will be the southern regions which will be covered with snow, and the northern regions which are visited by heat, light, and life.

11. If analogy is not a deceptive guide, what can we conclude from this close similarity of the poles of the Earth and of Mars? We can conclude that Mars, like the Earth, has its snows and polar ice, which extend during the winter, and partly melt in the summer heat and recede towards the pole. On Earth, the partial fusion and the extension of the snow-covered domes come every 6 months, while for Mars, whose year is longer, they come every 11 months. The southern snowcap of the Earth is larger than the northern. The same applies to Mars. Both planets reach the farthest point of their orbit when it is winter in their southern hemisphere. For both the winter of the southern hemisphere comes at the epoch of the aphelion, and the winter of the northern hemisphere at perihelion. The cold is, therefore, more intense in both planets in the southern hemisphere than in the northern hemisphere on account of the greater distance from the Sun during the southern winter. This produces the predominance of southern snows in both planets.

12. The inclination of the axis of Mars is nearly equal to that of the Earth's axis, being 61 degrees instead of 67. Mars therefore has a torrid zone, a temperate zone, and a frigid zone just like the Earth. It has seasons, including spring, summer, autumn, winter, analogous to our own, only about twice the length on account of the longer year. The Sun, seen from Mars, is reduced to one-half by its greater distance. Its disk has a surface



O. The two Hemispheres of Mars.

[To face p. 264.

amounting to only 43 per cent. of the surface we see from here. Heat and light are, therefore, half as strong as on Earth, unless a special kind of atmosphere modifies the result of distance. In any case, the presence of an atmospheric envelope round Mars is beyond doubt ; the presence of polar snows implies the presence of water, and the latter can in any case not fail to produce an atmosphere of vapour. But in addition we know that Mars possesses an aerial envelope, limpid like our own and susceptible like ours to illumination by the rays of the Sun. This is proved by the following observations. The patches of Mars, whether red or green, continental or oceanic, are only visible when they occupy the central portion of the disk. Near the edges of the planet they seem submerged under a luminous curtain which spoils their sharpness. They may totally disappear before reaching the extreme edge of the planet. Finally, the outline of the planet is sometimes so much brighter on the rest of the disk that Mars appears surrounded both east and west by a narrow border of bright light. From this we may conclude the presence of an atmosphere which is illuminated like our own under the rays of the Sun, and produces daylight on the planet. The luminous border round the planet and the luminous veil which hides the patches near the edges are just that atmosphere traversed by our gaze under a great obliquity, and therefore through a great thickness. The radius of Mars is about one-half the Earth's radius ; it is 12,500 miles round, and its volume is about one-seventh that of the Earth. Seven globes like that of the Moon joined together would represent the thickness of Mars. Apart from its smaller volume, Mars is the planet which resembles the Earth most closely.

TWENTIETH LESSON

THE PLANETS (*Continued*)

The asteroids; their number. Pigmy worlds, 1.—A broken planet, 1.—Names of the first twenty asteroids, 2.—Jupiter, its appearance, 3.—The Earth and the Sun seen from Jupiter, 3.—The year of Jupiter, 3.—Speed of rotation of Jupiter and polar depression, 4.—Relation between polar depression and speed of rotation, 4.—Polar depression insensible on the Sun, the Moon, and various planets, 4.—Seasons and days of Jupiter. A perpetual spring, 5.—Cloud belts and the trade winds, 5.—The satellites of Jupiter. Their eclipses, 6.—Roemer and the speed of propagation of light, 7.—Saturn. Its appearance, 8.—The Earth and the Sun seen from Saturn, 8.—The year of Saturn. Its seasons, 8.—Saturn's satellites and rings, 9.—The rings seen from Saturn, 9.—Saturnian nights, 9.

1. BETWEEN the orbit of Mars and that of Jupiter there is a zone occupied by a swarm of small planets. These are known as asteroids, or telescopic planets, since they can only be seen with a telescope. The number known to-day exceeds 200, but everything goes to show that future observations will discover new ones. A profound study of celestial mechanics tells us even that the asteroids should be counted by the thousand. The most striking characteristic of these planets is their extreme smallness. The largest of them, Juno, Ceres, Pallas, and Vesta, have radii of only 125 to 250 miles. Amongst these dwarf planets, the veritable dust of the skies, there are some whose radii are only a few miles long, and which we could walk round in a day. The smallest of our districts

has a greater surface than some of these strange worlds. Another special characteristic of the asteroids is the confusion of their orbits. The large planets revolve round the Sun in about the same plane as balls might roll round a central point on a smooth surface. The telescopic planets make an exception to this law. Their orbits are generally greatly inclined to the common plane of the orbits of the principal planets; and instead of being exactly enclosed one within another, they interlace, cross, and intertwine like a heap of hoops assembled at random. The small volume of the asteroids, their number and their conglomeration in the same region of the heavens, their angular and fragmentary aspect, the interlacing and inclination of their orbits, all go to show that these small bodies are the pieces of an original planet, thrown in every direction by the sudden development of explosive forces. A single planet similar to the large planets of the solar system must have circulated originally between Mars and Jupiter. At an epoch which cannot be fixed by astronomical chronology, an explosion of which the Earth presents feeble examples in the play of subterranean forces shaking the continents and sometimes dislocating them, must have occurred in the heart of that planet and projected its broken fragments into space. This bold hypothesis was put forward by Olbers, a very famous astronomer, to whom we owe the discovery of Pallas and Vesta.

2. We know nothing concerning the physical constitution of the telescopic planets, nothing about their seasons, and nothing about their daily rotation. Distance and smallness of volume hinder observations which would give us that information. Flora, the asteroid nearest the Sun, is at a distance of 210 million miles from the

Sun, and traverses its orbit in 1,193 days. Maximiliana, the most distant, is 325 million miles from the Sun, and its year lasts 2,310 days. Here are the names of the first 20 asteroids, according to their date of discovery :—

Names of the Asteroids.	Discoverer.	Date of Discovery.
Ceres	Piazzi	1801
Pallas	Olbers	1802
Juno	Harding	1804
Vesta	Olbers	1807
Astræa	Hencke	1845
Hebe	Hencke	1847
Iris	Hind	1847
Flora	Hind	1847
Metis	Graham	1848
Ilygia	De Gasparis	1849
Parthenope	De Gasparis	1850
Victoria	Hind	1850
Egeria	De Gasparis	1850
Irene	Hind	1851
Eunomia	De Gasparis	1851
Psyche	De Gasparis	1852
Thetis	Luther	1852
Melpomene	Hind	1852
Fortuna	Hind	1852
Massalia	De Gasparis	1852

3. From the swarm of pigmy planets we come in order of distance to Jupiter, which is 1,414 times more voluminous than the Earth. The colossal planet here appears to us as a simple star of yellowish white colour and great brightness, but yet inferior to Venus. The 500 million miles which separate us from it reduce Jupiter almost to a single bright point ; but if the giant were closer it could hide a considerable part of the heavens from us. At the distance of the Moon, for instance, it would cover 1,200 times the area occupied by the latter, and 10 times the width of its disk would cover the sky

from the extreme west to the extreme east. The reduction by distance is reciprocal. The apparent size of a planet being reduced by the same amount as the apparent size of the Earth as seen from it. If Jupiter appears to us like a star, what must the earth look like seen from Jupiter? Probably as a little speck, scarcely seen in the shades of the heavens.

According to the point it reaches in its orbit, the distance of Jupiter from the Sun varies from 470 to 517 million miles. Its mean distance is about 5 times that which separates us from the central body. At this distance, the Sun appears 5 times less large than it does to us, and therefore 25 times less in area, which means that its heat and light are reduced 25 times. It must be a very sad little Sun, with its little pale disk less than the size of a hand.

Jupiter's year is, therefore, as long as a dozen of ours, meaning that the planet turns round the Sun once while the Earth turns 12 times. The immense size of its orbit is the cause of this slowness, which is only apparent, since Jupiter covers 30,000 miles in an hour.

4. The Earth turns on its axis in 24 hours, so that a point in its equator covers 1,530 feet per second. That is approximately the speed of a gunshot. In order to accomplish its rotation round its axis, Jupiter only takes 10 hours and 5 minutes. Thus an equatorial point of the gigantic globe covers, in one second, 41,500 feet, or 20 times as much as a point on the terrestrial equator. This excessive speed must result in a considerable deformation at the poles of the planet. When a sphere turns round its axis it develops, as we have seen in a previous lesson, a so-called centrifugal force by the mere fact of its rotation. This produces a bulge at the equator, and

a depression at the two poles, provided the substance of the sphere has a certain flexibility. It is thus that, on the supposition of a general original fluid, we have explained the bulging of the Earth at the equator and its polar flattening. Centrifugal force is the greater the more rapid the rotation. Thus, if Jupiter has ever been in suitable conditions of flexibility, it must have been deformed more than the Earth. And, indeed, on examining the planet in the telescope, its disk does not appear round, but very sensibly flattened. Careful measurement tell us that the polar depression amounts to 2,000 miles at each pole on the planet. For the Earth's poles it is only 12 miles.

The polar flattening is, no doubt, a fact common to all the bodies of the solar system, since they all turn on their axes. But, on account of their slow rotation, it is sometimes too feeble to be observed from the Earth. The Sun and the Moon, which turn on their axes in 25 days and 27 days respectively, show no appreciable deformation. Mercury, Venus, and Mars, who rotate approximately in the time employed by the Earth, have volumes too small in relation to their distance to enable us to observe any slight irregularity of their poles. In any case, Jupiter provides us a clear proof of the intimate relation between speed of rotation and polar depression, and this is confirmed by an examination of Saturn.

5. The axis of Jupiter, instead of being more or less inclined, as in the case of the preceding planets, is vertical, or nearly vertical, on the plane of its orbit. The planet, therefore, constantly presents its equator to the rays of the Sun, and therefore has no periodic seasons. From one end of its year of 12 years to the other it is continual spring, a temperature without variations.

Our month of March, the time when the Earth also presents its equator to the Sun, would, if perpetually prolonged, but made 25 times less warm, give us an idea of the monotonous climate of Jupiter, unless atmospheric conditions of an unknown character intervene. Such an endless spring consists of days and nights which are always equal from pole to pole of the planet, both days and nights lasting 5 hours each.

The telescope shows us on the disk of Jupiter some irregular bands alternately bright and dark, parallel to the equator of the planet. It is probable that the brilliant bands are belts of clouds lined up in the direction of rotation of the planet by air currents corresponding to our trade winds, occasioned by the rapid rotation of Jupiter. As regards the dark bands, they probably correspond to shadows of clouds on the ground seen across a clear portion of the atmosphere.

6. We have called those secondary bodies which circulate round certain planets like the Moon round the Earth "satellites." Mercury and Venus have no satellites; but the nights of Jupiter are illuminated by five moons, three of which are considerably larger than ours. Sometimes alone, or in twos or threes, or all together, the companions of the great planet rise above the horizon and are seen as crescents, half-moons, or full moons, and endow the night sky of Jupiter with a magnificence of illumination unknown on Earth. The nearest revolves round the planet in 42 hours and 28 minutes, and the most distant in 16 days, 16 hours, and 32 minutes. While revolving round Jupiter the satellites turn on their axis, and the two revolutions have a similar duration, so that these moons present to the planet the same face always, just as the Moon does to the Earth. That seems to be

a general law: each satellite takes the same time for rotating on its axis as it does for revolving round its planet.

To us, Jupiter's five moons reduce themselves to little luminous points placed in constantly changing positions close to the planet itself. We see them passing in front of the planet, traversing its disk, leaving it, coming to the left, going back, disappearing behind the planet, and reappearing some time after. At the moment when it passes between the Sun and Jupiter, each satellite projects its shadow on the brilliant disk of the planet, producing a round black spot. For those regions of Jupiter which are covered by that spot there is an eclipse of the Sun. When a satellite passes beyond the disk it enters the cone of shadow of the planet, and becomes invisible or eclipsed, absolutely as our Moon does when it plunges into the shadow of the Earth. Astronomical telescopes permit us to follow all the circumstances of those distant eclipses from here. When the Earth is in a favourable position the cone of shadow cast by Jupiter is, to a great extent, under our eyes, and an observer sees sometimes one satellite, sometimes another, penetrate into it at each revolution, disappear for the time required to traverse it, and reappear with all its brightness at the other end of the shadow. Every time it passes behind the Earth our Moon does not penetrate into the Earth's shadow, and thus it is not eclipsed, since its orbit is strongly inclined to the plane in which the Earth revolves. The moons of Jupiter, on the other hand, are eclipsed at each revolution, since they turn nearly in the same plane as the planet.

7. It was by means of the eclipses of the satellites of Jupiter that Roemer, in 1675, succeeded in solving one

of the most beautiful problems of celestial physics, the problem of the speed of light. This is how he did it. One of the five satellites revolves round the planet in 42 hours 28 minutes. Now this same time elapses between two of its consecutive reappearances outside the cone of shadow of Jupiter. Let us suppose that, at a

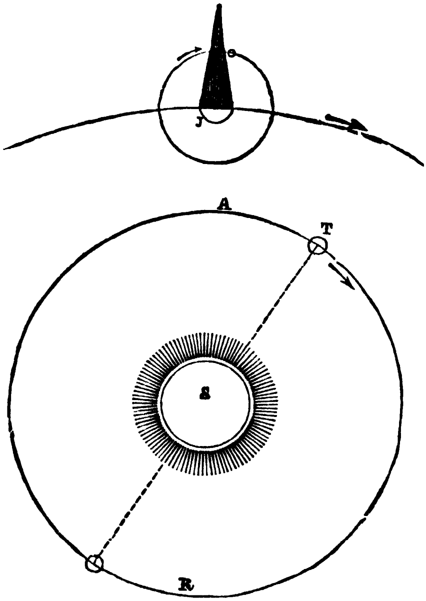


FIG. 73.[1]

time when the Earth is near the point A of its orbit (Fig. 73), an observer marked the exact time when the satellite emerges from the shadow. After 42 hours 28 minutes there will be another reappearance of the same satellite out of the shadow; after twice, three

[1] S is the Sun, T is the Earth, J Jupiter with its cone of shadow into which the eclipsed satellite plunges. A little to one side the same satellite is shown emerging from the shadow.

times, nine times that same duration, there would be a third, fourth, or tenth reappearance. It is therefore possible to calculate beforehand the exact time at which such a reappearance must take place. Let us suppose that the precise epoch of the 100th reappearance is thus calculated. When that epoch has come, the satellite is observed, and we find, to our astonishment, that in spite of the admirable regularity of celestial movements the calculation is not in accordance with observation, since the reappearance does not take place at the instant predicted. In order to observe it, it is necessary to wait a little longer than one-quarter of an hour, about 16 minutes. What produces this strange retardation? You will notice that it requires six months to wait for the 100th reappearance of that satellite. During that time the Earth passes over half of its orbit, and arrives at the point R at the opposite end of its orbit. During these six months Jupiter, being much slower in its revolution round the Sun, has not been sufficiently displaced to oblige us to take its movement into account, and we can suppose that it remains in the same position. Therefore the light starting from the satellite at the instant when it emerges from shadow must, in order to come and inform us of the end of its eclipse, traverse an additional distance equal to the diameter of the Earth's orbit, say the distance from A to R, which is about 190 million miles. That is the cause of the retardation. Since the amount of distance to be covered is increased, the time taken to cover it is also increased. Thus we know that in order to cover a distance of 190 million miles, light requires about 16 minutes. To cover half that distance, which is the distance between the Sun and the Earth, it requires 8 minutes.

8. Saturn is 734 times as bulky as the Earth. It is half the volume of Jupiter. Yet it produces but a poor effect upon our eyes. We see it as a pale star of a leaden appearance. The Earth must look very small from there if it is visible at all. It is at least certain that considering the distance the Sun is reduced to a disk 100 times less in surface than the disk which lights our days. If the Sun, the source of all the splendours, the giant king of the world, is reduced for Saturn to the insignificant proportions of a half-penny piece, how must the Earth appear from Saturn ? Saturn takes 29 years to complete its orbit, with a speed of 2,300 miles per hour. Its average distance from the Sun is 900 million miles. It rotates on its axis in 10½ hours. Its rapidity of rotation produces, as in the case of Jupiter, a considerable flattening at the poles. In the case of Saturn, the value of that polar depression amounts to one-tenth of the radius of the planet, or about 3,500 miles. The feeble density of the material of the planet, no doubt, has some effect in its enormous flattening at the poles. In a previous lesson we have seen that the average weight of Saturn is only seven-tenths of the weight of the same bulk of water, so that the planet could float on that liquid. It is certain, on the other hand, that its density must grow from the surface towards the centre, towards which the heavier material tends to concentrate. The superficial layers of the planet must, therefore, be made of a very light substance of particularly low density. What idea can we get of this world where the soil, instead of consisting of rocks, is made of material lighter than elder pith ? Are oceans possible on such a ground without consistency ? The laws of equilibrium say no. There can be no comparison between the Earth, Venus, Mars, and the colossal

planets relegated to the confines of the solar system. By the enormity of their volume, their lightness, their speed of rotation, and their immense polar depression, they constitute worlds by themselves.

A telescope gives us very little information concerning Saturn. We see on its disk some luminous bands, mingled with dark bands parallel to the equator, much as we saw similar bands on Jupiter. Can these also be cloud belts due to trade winds which the rapid rotation of the planet produces in the planet's atmosphere? Perhaps. Let us add that the axis of Saturn is inclined at 64 degrees, or nearly as much as the Earth. The seasons of the great planet are, therefore, similar to our own, except that each of them lasts seven years. Seven years of winter without a break would be very long for us, especially if the sun were 100 times less warm than it is here.

9. Of all the planetary globes, Saturn is the most rich in satellites. It has eight to illuminate its nights. The nearest turns round the planet in 22½ hours, and the most distant in 79 days. Titan, the largest of them, has a bulk 9 times that of our Moon. But this is not all. Saturn possesses a ninth satellite, which is unique in the solar system. It is a circular ring, flat, very wide, and relatively very thin, which surrounds the planet in the middle without touching it anywhere. It is not continuous, but composed of three concentric zones—one is of a greenish tint, and the middle one is brighter than the disk of the planet itself. The two last zones are clearly separated from each other by a wide interval through which one could see the starry heavens. It is presumed that their material is of a cloudy nature, since traces of sub-divisions are sometimes seen which indicate an easy separation. The total width of the three zones is 3,000

miles, and the empty space which separates the ring from the planet is 80,800 miles. As regards the thickness of the ring, it is estimated to be 200 miles at the most This satellite ring accompanies Saturn in its rotation It turns round the planet at the same time as the latter turns round its axis, just as if the two made up a single body.[1]

The science of movement shows that this equality of rotation is indispensable for the conservation of the fragile edifice of the ring, which otherwise would fall to pieces under the influence of gravity, and would project its gigantic ruins on to the planet. By itself, the ring is not luminous, for we see it projecting its shadow on the planet just as we see the planet projecting its shadow on the ring. It simply reflects the light coming from the Sun. It is, therefore, as regards Saturn, a Moon of exceptional shape, embracing the whole sky, like a continuous chain of satellites. The ring is not seen from the poles of the planet on account of the curvature of the soil. From 66 degrees of latitude it commences to be seen on the horizon. Near the equator it appears in full like an immense luminous arch, projecting from one end of the sky to another. At the equator itself it is seen edgewise, and it takes the aspect of a silver thread cutting the sky at the zenith. Imagination is unequal to the task of picturing the fairy illumination of Saturn at night, when the ring, in a favourable perspective, curves its belt of light from east to west, and the eight satellites, in various phases, mingle their white radiance with its light.

[1] The ring is now considered to consist of a swarm of meteoric stones separated from each other, the outermost moving at a slower rate than the innermost, and their rates being the rates at which satellites at the same distance from the planet would revolve.—Tr.

TWENTY-FIRST LESSON

THE PLANETS (*Concluded*)

Uranus : its discovery, its year, its seasons, its satellites, 1.—Mutual attraction of the planets, 2.—Perturbations of Uranus, 3.—A planet predicted by theory, 3.—The eye of calculation and the discovery of Neptune, 3.—Neptune : its distance, its year, its weight, 4.—The Sun seen as a star, 4.—The outskirts of the Sun's domain, 4.—The mineralogy of the skies, 5.—Shooting stars. A star cannot fall from the skies, 6.—The 10th of August and 12th of November, 7.—St. Lawrence's tears, 7.—Some showers of shooting stars, 7.—Meteorites, their volume and their speed, 8. —Meteorite swarm and rings, 9.—Assteroids which stray into our atmosphere, 9.—Explosion and fall of meteorites, 10.—Celestial pebble of 20,000 cwt., 10.—Extra-terrestrial matter, 10.

1. THE planets Mercury, Venus, Mars, Jupiter, and Saturn have been known from the earliest antiquity, although the satellites of the latter were unknown. The asteroids, the satellites of Mars, the satellites of Jupiter and Saturn, and the planets of Uranus and Neptune are acquisitions of modern astronomy. Uranus was discovered in 1781 by Herschell, one of the astronomers who have contributed most to the science of the skies. The planet appeared to him in his powerful telescope like a small disk of uniform pale appearance, which gradually changed its place among the neighbouring stars. It was, therefore, a new planet, which up till then, on account of its feeble luminosity, had escaped being seen. The star had been measured and weighed, its orbit determined, its distance from the Sun calculated, and its satellites discovered before it had completed one revolution

It is only rarely that Uranus is visible without an instrument. In favourable circumstances it appears to the naked eye as a star of the sixth magnitude at the most. This invisibility is not caused by its smallness of size, since the planet is 82 times larger than the Earth, but it is due to its excessive distance. Uranus is 1,820 million miles away from the Sun. It takes 84 years to complete its orbit. A year of Uranus is, therefore, equal to a whole human life. It apparently turns on its axis with great speed, for the telescope finds an enormous depression at its poles, a flattening equal to one-tenth the radius of the planet. But since it is too far away we cannot discover any detail, nor find any patch on its disk which would allow us to determine its rotation and the time it takes. It is supposed that the axis of rotation rests nearly in its orbit, so that the planet in 42 years' time will present each of its poles vertically to the Sun, and thus will produce even more strange seasons than those of Venus. We also know that for Uranus the disk of the Sun is 300 or 400 times smaller than for us. We know that its mean density is slightly inferior to that of water, and we know, finally, that eight moons circulate round the planet in a plane perpendicular to the plane of its orbit. That is where our knowledge ends. It is too far away to determine the rest.

2. The discovery of Neptune is the most striking proof of the precision of modern astronomical theory. Let us try to understand it.

Attraction is a common property of all bodies, great and small, but its amount is proportional to the mass. On account of its preponderance of mass, the Sun attracts all planets towards it and curves their orbits. The planets, in turn, attract their satellites and make them

turn round them. The Earth attracts the Moon, as the Sun attracts the Earth. Indeed, it is evident that the Earth's attraction will also be exerted outside the orbit of our satellite, though to a decreasing extent according to the law of inverse squares, for why should its effects be suddenly annihilated? The Earth, therefore, acts on the neighbouring planets—on Mars, Venus and the others. Only its action, very much diminished by distance, cannot compare with that of the Sun. In any case our Globe exerts a certain influence on Mars, for instance, however small that influence may be. If Mars obeyed the attraction of the Earth, what would happen? It would abandon its circular route round the Sun, and approach our Globe in order to revolve round it, and we should have another Moon, the planet abandoning its course to enter the ranks of the satellites. On the other hand, since the laws of the heavens are rigorously impartial, the Earth tends towards Mars, which attracts it, and tries to make a moon of it. Jupiter also attracts us in order to increase the number of its own satellites. Saturn attracts us in order to make us part of its ring. Venus, Mercury, and indeed all the planets do the same, down to the smallest asteroids. But our pride need not be lowered, since the Earth on its part exerts the same action on Jupiter, Saturn, and the others, however many they are. There is, therefore, an incessant struggle between the planets. Each of them, in proportion to its mass, and inversely in proportion to the square of its distance, acts upon its neighbours and tries to appropriate them. But the master is there, the powerful dominating Sun, and the submissive planets keep their respective places. Never will one of them become the satellite of another. Yet something remains

of these reciprocal pulls. One planet, solicited by the neighbourhood and considerable mass of another, deviates slightly from its straight path, only to return to it sooner or later under the orders of the Sun. These deviations of the planets from their fundamental paths, produced by the attraction of neighbouring planets, are called perturbations. They are the greater in proportion to the size of the body producing the deviation, or as the perturbing body is nearer or larger.

3. We can thus understand that in order to determine the precise course of any given planet, and find out at what point of the sky it will be at such-and-such an epoch, astronomers must not only take into consideration the attraction of the Sun, but also the perturbing effects of neighbouring planets. If their calculations are exact, and every planet is taken into account, then observation must always agree with astronomical theory, and the celestial vagrant must, at any given date, occupy that point in space which science assigns to it. But ever since its discovery, Uranus showed a flagrant disagreement with astronomical theory in its observed positions; the rebel planet never was at the point calculated. It was in vain that the perturbing action of the two neighbouring giants, Saturn and Jupiter, was taken into account; unexpected deviations always made the calculation wrong. Then a suspicion arose in the minds of the astronomers, a great suspicion which, on the sole basis of the disturbed course of Uranus, predicted a new world in the extreme depths of the solar system. Beyond Uranus, an unknown planet must exist, which drew, by its attraction, the other planet out of its course. An illustrious French geometrician, Le Verrier, undertook the task of verifying this suspicion, and discovering the

perturbing star with the sole aid of theory. Up till then, astronomical observations had been made by the patient exploration of the skies. The able theoretician changes the method. His instrument of research is the pen, and his instrument of observation is the eye of calculation. And here we see him bringing together learned formulæ, expressing the laws of the sky. We see him putting down the weight, volume, speed, and distance of the disturbed planet and the disturbing planets, both known and unknown. The result of these conceptions was wonderful. On 31st August, 1846, Le Verrier announced to learned Europe that the perturbing planet should be found at a certain point in the skies and having a certain magnitude.[1] Following this announcement, the director of the observatory at Berlin, M. Galle, pointed his telescope during the next few days at the part of the heavens assigned; the planet was there in the exact place indicated by the finger of theory. Without looking at the sky, science had obtained a clear view of the heavens! Never had the eternal laws of Geometry scored such a complete triumph.

4. Neptune was first called the planet of Le Verrier. This planet is never visible to the naked eye, although it is 110 times more voluminous than the Earth. In the telescope it appears as a small bright point comparable to a star of the eighth magnitude. Hardly do the best telescopes show any sensible size. A distance of 2,793 million miles separates it from the Sun, round which it accomplishes a revolution in 164 years. Neptune is accompanied by a satellite which revolves round it in 5 days and 21 hours. From the speed of revolution of

[1] A similar calculation was made independently by J. C. Adams at Cambridge.—Tr.

that satellite, astronomers have been able, by the method I have already explained, to calculate the mass and density of Neptune. We thus know that Neptune is 21 times heavier than the Earth, and that its mean density, comparable to that of Jupiter, hardly surpasses that of water. To weigh a heavenly body situated on the confines of the solar system, to determine the fundamental character of its material, when the body itself, 110 times more voluminous than our Earth, is so much diminished by distance that the best telescopes only show it to us like a millet seed, is not that a noble expression of human understanding ? Science has nothing to add to these results of mechanical speculation, since the extreme distance of the planet makes it impossible to tell anything concerning its physical condition. In order to end the story of Neptune, we need only say that the disk of the Sun appears 1,000 times smaller on Neptune than it does as seen from the Earth. The prodigious furnace of the solar system is, therefore, for Neptune but a star slightly brighter than the others. What sort of illumination, of daylight or heat, exists on that distant planet ? We must draw no hasty conclusions, as all is unknown.

Have we attained the final regions of the solar system in the orbit of Neptune ? Are there no planets beyond ? There is nothing yet to confirm or deny this. Though fairly well known in its nearer regions, the solar system leaves a great field open to speculations in its middle and external portions. Perhaps there are beyond Neptune, in distant inexplorable regions, planets revolving in enormous orbits. And who can say but that between Mars and the Sun other planets may be circulating, rendered invisible by the immediate neighbourhood of

the solar splendours. But let us leave the uncertain domain of probabilities. Whether the family of planets is limited by Mercury on the one hand, and Neptune on the other, matters but little in reality. Even as we know it, the solar system impresses our minds with its formidable amplitude.

5. Astronomy furnishes us with precise data concerning volume, distance, mass, year, seasons, satellites, etc., of the Earth's companions which we have just passed in review. But these data, nearly all of which are mechanical or geometrical, are not those which impress us most. We are much more interested in the physical constitution of the planets, of which we know yet so little. We learn, for instance, with great surprise that snow covers the two poles of Mars and that volcanic craters are scattered over the surface of the Moon. A pebble picked up at our feet is of little interest to us, since it belongs to the Earth. But if we were sure that that pebble had descended from the sky, and that it had belonged to Jupiter, Mars, or Saturn, then who would remain indifferent face to face with this sample of celestial mineralogy? To see the material of the heavens close by and to submit a fragment of a planet to analysis, what satisfaction that would be for our legitimate curiosity! We should know the substance of the heavenly bodies, of those wonderful bodies which, clothed in light, make the glory of the firmament! Well, this celestial pebble is not a vain supposition. Great pieces of rock have rained upon us from the sky, from the interplanetary space, blocks of stone sufficient to crush a house in falling. Do they come from the planets? No, but certainly their origin is not terrestrial. They are real specimens of the mineralogy of the heavens, as we shall see.

6. We all remember those sudden sparks which, at night, seem to detach themselves from the vault of heaven and rush across the skies in luminous tracks, vanishing as suddenly as they appeared. They are commonly called shooting stars, being supposed to be stars which change their places in the sky. Can the stars then really wander about right across the firmament ? And can they fall upon the Earth ? If we only considered appearances, and saw in the stars nothing but tiny sparks fixed in the vault of heaven, it is natural to believe that they could detach themselves and fall on the Earth like over-ripe figs fall from the tree. But we know that that vault is an illusion. We know that a heavenly body can be enormously large, incomparably superior to the Earth, though appearing to us only as a simple bright point, or even scarcely visible. Are the stars, then, farther away than Neptune, which is 110 times bulkier than the Earth, and yet invisible without strong telescopes ? Then what must be the size of the stars if, from the distance where they are, they send us such brilliant rays ? They must be as large as the Sun, or even larger. If a single star fell on the Earth, what would happen to our Globe under the shock of the giant precipitated from the skies ? Crushed, like a grain of sand under a heavy hammer, the Earth would scatter its materials into space. Let us imagine the Earth and a piece of rock attracting each other at a distance. Which of the two would precipitate itself upon the other ? Obviously the smaller one, the piece of rock. Similarly, if we could suppose that one of them should fall on the Earth, it would surely be the little Earth which would fall upon the greater star ? To assume the contrary is like supposing that the Earth would fall towards the

pebble, and not the pebble towards the Earth. The stars, therefore, do not fall. That is quite certain. They do not rush across the sky with amazing speed. Then what are shooting stars?

7. There is hardly a night without shooting stars. On the average, there are from four to eight per hour. But at certain epochs of the year, especially towards the 10th of August and 12th of November, the number increases to an astonishing extent. At that time there are veritable showers of shooting stars. The time of the 10th of August has been noted even by persons to whom such observations are foreign. In some localities the shooting stars of that period are called St. Lawrence's tears, the simple-minded population having compared those trains of fire with the burning tears of the martyr on the grid-iron. The feast of St. Lawrence, as a matter of fact, is on the 10th of August. Let us recall some samples of these extraordinary apparitions. In a single night of 10th August, 1839, 1,000 shooting stars were counted in 4 hours at Naples, 87 in three-quarters of an hour at Metz, 819 in 6½ hours at Parma, and 500 in 3 hours at Newhaven, in the United States.

The 12th of November, 1799, a shower of shooting stars was observed at Cumana, in South America, which resembled fireworks at an immense height, shooting towards the east. Myriads of shooting stars incessantly filled the sky with phosphorescent tracks. Flaming globes like enormous red bullets fired by some celestial artillerist traversed the crowd of stars with a terrible speed. For 4 hours the same spectacle was repeated at distant points of the Earth, from the equator to the pole. The heavens were on fire.

On the 12th November, 1833, from 9 o'clock in the

evening till surnise, one of the most extraordinary showers of shooting stars was observed along the east coast of North America. They radiated like rockets by the thousand from the same point of the sky in every direction, sometimes in sinuous lines, and sometimes in straight lines. Many exploded before disappearing. Some had the brightness of Jupiter or Venus. It was impossible to count them, since they fell like snowflakes in a blizzard. Yet when the shower was diminishing an observer in Boston tried to count them approximately. In 15 minutes he counted 866 in one-tenth of the sky, which means 8,660 for the whole visible sky, and 34,640 for 1 hour. Now the shower lasted for 7 hours, and was only counted when it was abating. It is, therefore, clear that the number of shooting stars seen in Boston alone must have been over 240,000. It is not surprising, therefore, if the total number of shooting stars appearing every year on the entire Earth is estimated at several million.

8. Globes of fire similar to those accompanying shooting stars at Cumana are also seen singly. They are then called aerolites. Their bodies are generally round in form, sometimes of a size equal to that of the Moon, or even larger, which suddenly traverse our sky, projecting a brilliant light, and disappearing in a few seconds as suddenly as they came. They often leave a trail of sparks in their path, while some have been known to burst with tremendous report and throw their hot fragments on to the ground. These fragments are called meteorites, or stones fallen from the sky. Astronomers have tried to calculate the real size and speed of aerolites as far as the rapidity of their appearance permitted. The results obtained differ very much from one aerolite

to another. Some of them have been estimated at 30 or even 100 yards in diameter, and others at 2 or 3 miles. But their most striking characteristic is their prodigious speed. A meteorite observed on the 6th July, 1850, covered 47 miles in a second, which is more than double the distance covered by the Earth in its orbit, that distance being 19 miles a second. The least rapid of those whose velocity has been determined had a speed of 8,000 feet per second. A bullet would have been 6 or 7 times too slow to follow it. To sum up: We may say that several of the meteorites move with a speed superior to that of a planet in space. The same result applies to shooting stars, whose speed is comparable to that of the Earth, being from 7 to 20 miles per second.

9. In order to explain shooting stars and meteors, astronomers suppose that several swarms or rings of asteroids of very small dimension revolve round the Sun. An examination of the solar system has shown us extreme conditions in the size of the planets from Jupiter and Saturn down to the telescopic planets beyond Mars. The probabilities are very great that space is strewn with still smaller bodies, some of which are barely the size of some small island of our Globe. Interplanetary space seems to be filled with a veritable planetary dust, whose grains may be comparable to a piece of a mountain, a fragment of rock, an orange, or a nut. Let us assume, then, that these bodies of asteroids fly in innumerable numbers round the Sun in several swarms of approximately circular shape, one of which, at least, approaches the Earth. Imagine the luminous band in a dark room containing a whirl of dust. Give to this whirl a movement of rotation round its centre and you will have an image of such swarms.

The Earth, let us say, is near a ring of asteroids. It is clear that the relatively immense mass of our Globe must produce strong perturbations on the course of those bodies when they come near us. The asteroid, seized by the Earth's attraction, gradually leaves its orbit, falls towards us, and plunges into our atmosphere with the lightning speed it had in its course round the Sun. The friction of the air, brought to excess by the rapidity of its flight, produces an elevation of temperature, and suddenly the celestial body, which was then invisible, becomes incandescent, and leaves a flaming trail of sparks behind it. Ordinarily the ever-increasing resistance of the air, combined with the obliquity of the fall, stops it at the first plunge. It then rebounds like a stone thrown slantingly into the water, and rushes out of the atmosphere in order to continue its disturbed course round the Sun. Indeed, those asteroids which are momentarily turned from their course by the Earth's attraction, and leave their swarm to enter the atmosphere which enflames them, constitute what we call shooting stars and meteorites. At certain times of the year, particularly the 10th of August and 12th of November, the Earth passes through the swarm itself, and this explains the periodical returns of showers of shooting stars.

10. The rebounding from the first layer of atmosphere is not always possible on account of the great obliquity in the direction of the vagrant. If the latter traverses the whole thickness of the air, then at a certain height, when the temperature becomes hot enough, it explodes with a noise of thunder, breaks into 1,000 fragments, and falls upon the Earth in a shower of stones. The force of projection of these stones is such that they are

driven into the earth more than a cannon-ball would be driven. Their blackish surface, which has a varnished look, shows signs of a commencement of fusion. Their weight is very variable ; some meteoric stones or aerolites are little more than grains of dust, while others weigh several hundred pounds. What, then, must be the volume of the great meteorite before it breaks.

The fall of aerolites is not at all rare, and observation has registered hundreds of cases. It is, therefore, quite true that stones fall from the sky, and we can obtain curious items of information on extra-terrestrial matter by examining them. Indeed, a remarkable consequence has resulted from the study made of these minerals from interplanetary space. No aerolite so far noticed has shown any substance which does not exist on the Earth. Iron, sulphur, phosphorus like ours, lime, silica, clay, copper, tin, etc., similar in every respect to ours, these specimens of mineralogy are common to the Earth. Iron predominates. Certain enormous blocks of pure iron are often known to be of celestial origin. Such is the meteoric mass observed near Thorn which weighs 20,000 cwt. at least. That block of metal must at one time have revolved round the Sun like a little grain of dust. It formed, no doubt, part of a swarm of meteorites. To-day this block of metal lies on the Earth and is accessible to the tools of the miner like any terrestrial lode. Thus extra-terrestrial matter, as shown by stones fallen from the sky, is identical with the matter we know that is within our neighbourhood.

TWENTY-SECOND LESSON

THE COMETS

Comets: their orbits and direction, 1.—Appearance of the comets. The formation of the tail, 2.—The comet of 1843. Dimensions of its tail, 3.—Dimensions of heads of comets, 3.—Cometary matter. It does not intercept starlight. It does not refract, 4.—Perturbations undergone by the comets in the neighbourhood of the planets, 5.—Lexell's comet traversing the system of Jupiter, 5.—Feeble mass of the comets, 5.—The foolish terrors of superstition, 6.—Little probability of an encounter between the Earth and a comet, 6.—The emendation of the calendar, 6.—Spider's web and the stone from a sling, 7.—No need for apprehensions, 7.—Comets with unclosed orbits, and periodic comets, 8.—Halley's comet, 8.—The calculations of Clairaut, 8.—Admirable agreement between theory and fact, 8.—Biela's comet, 9.—Encke's comet and the mass of Mercury, 9.—Number of the comets, 9.

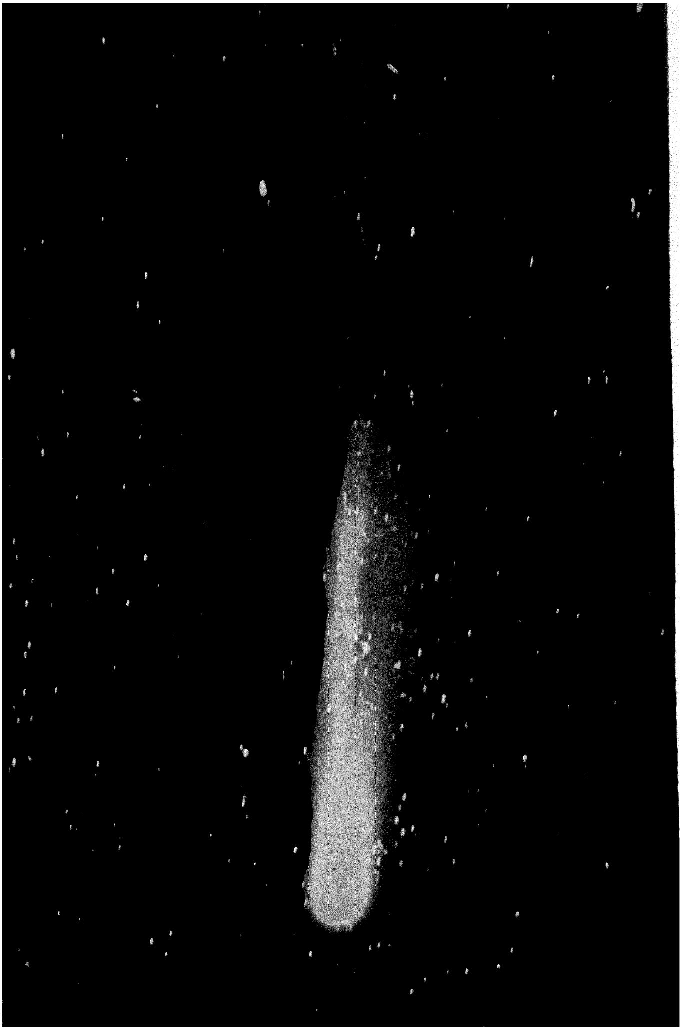
1. On account of their nearly circular orbits, which maintain them in revolution round the central Sun within our range of vision, the planets and the satellites are, for us, the really essential part of the solar system. At all times, to-day at one point, to-morrow at another, we find them again in the starry vault; but to this company of bodies, faithful to our skies, others are added from time to time, strange and enormous bodies coming from nobody knows where, plunging back again, after a short time, into the unsounded depths of the sky. These are the comets.

We generally distinguish in a comet the nucleus, the coma, and the tail. The nucleus is the essential portion

of the comet. Its brightness is greatest there, apparently owing to a greater concentration of matter. It is enveloped in a voluminous nebulosity, a sort of luminous mist, which is sometimes called the coma. The comets owe their name of " hairy stars " to that peculiarity. Finally, the tail is a luminous appendage of variable shape and length with which most comets are endowed. Yet a new body can appear without either coma or tail, and still be a true comet. What marks out comets particularly is the extreme length of their orbits, which, after having brought them more or less close to the Sun, bear them away to distances where they cease to be visible, even with the best telescopes. Like the planets, the comets move in ellipses round the Sun as a focus; but these orbits are so stretched out sometimes that, having almost touched the surface of the Sun, they rush out as far as Neptune on the outskirts of the solar system. And we may add that several comets seem to stray in space from one Sun to another in orbits which are never closed. If the chances of their voyages bring them into our neighbourhood, they approach our Sun under the influence of its attraction, and after having completely traversed its retinue of planets they rush off again, never to return. On leaving us they, no doubt, go to visit other suns, until one of them gathers it into its empire, by forcing it into a closed orbit.

A second mechanical characteristic distinguishes the comets from the planets. The latter all move in the same direction from right to left for a spectator watching them from the North Pole of the Sun. Besides, their orbits are nearly all in the same plane, which is also the plane of the Sun's equator.[1] No planet is seen outside

[1] Asteriods deviate considerably from this plane.



P. Halley's Comet.

29 May 1910.

[*To face p.* 292.

the narrow zone of the Sun which corresponds to this plane. To look for planets in the neighbourhood of the celestial poles, among the stars of the Bear or of the Hydra, would be a vain undertaking. The region they occupy is intermediate between these two extreme constellations. The comets, on the other hand, show every possible degree of inclination in their orbits. They are seen indifferently in all parts of the sky—the region of the poles, and also in the planetary zone. They move sometimes in the same direction as the planets, sometimes in the opposite direction.

2. When the distance of a comet surpasses certain limits, there is nothing to show that it is there at all. No predictions or calculations will avail us. The strange heavenly body which visits this part of the sky for the first time is always unexpected. Some evening it surprises us by its appearance. Some vigilant astronomer sees it in the field of his telescope. It is a white nebulosity of undecided and rounded appearance, with a greater brightness in the centre than at its borders; nothing more. But on approaching the Sun the nebulous body changes its shape; from having been round it becomes oval, then it stretches out and expands a part of its nebulosity in a direction opposite to the rays of the Sun which fall upon it; and, finally, the comet trails its immense tail behind it. It reaches its perihelion. That is its epoch of greatest brightness and the complete development of its luminous tail. As soon as the Sun is passed, the comet pursues its course on the second part of its orbit, moving farther away. Now its tail is directed away from the Sun, preceding the comet, instead of following it. From day to day it loses its brightness, and finally disappears sooner or later veiled by the

distance. Thus we see that the tail of a comet is not a permanent thing. It is formed at a certain time at the expense of the nucleus and coma, and its nebulous matter explodes in a gigantic shock. In the second place, the tail only appears in the vicinity of the Sun. It is probably an effect either of the heat or some other force emanating from the Sun, for it is always directed away from the Sun's rays, following the comet when it is approaching the Sun, and preceding it as it recedes. More rarely the comet expands on both sides of the nucleus. It has then on one side several aigrettes called the beard, on the other side its tail properly so called. But even in this case the direction of the luminous trails is determined by the position of the Sun. The aigrettes of the beard are turned towards it, and the tail away from it.

3. The tails of comets take up very different configurations. Sometimes the tail may appear like a straight beam or a pencil of faint light, sometimes curved like a threatening scimitar, or opened out like a fan. Its dimensions are sometimes prodigious. The tail of the great comet of 1843 was 150 million miles long and 3 million miles wide. If its head had been near the Sun it would have passed the Earth and swept into the orbit of Mars, while its width would have included the orbit of the Moon, and, indeed, a circle six times larger than that. It is true that the comet of 1843 was exceptional in its dimensions, but tails of 25, 50, or 75 millions of miles are far from being rare.

These enormous trains flow from the body of the comet just as a shower of sparks rushes from the middle of a rocket. The cometary matter, driven apparently by some repulsive force emanating from the Sun,[1] travels

[1] Probably the pressure of light itself.—Tr.

along the tail and dissolves into invisible mist, of which each particle then pursues its course alone into the abyss of space. What must be the volume of comets to suffer such loss, and of what does their material consist to float thus from the sky? The head of Halley's comet during its appearance in 1835 was 354,000 miles in diameter, while that of the comet of 1811 was 1,130,000 miles. The latter surpassed the Sun itself in volume, while the former, by itself, would represent the volume of all the planets with their satellites 40 times over. The comet of 1843, in spite of the extraordinary dimensions of its tail, was smaller. The diameter of its head only amounted to 95,000 miles, which, however, represents a volume superior to that of Jupiter. The volume of a comet is therefore always considerable, and it often surpasses that of the greatest of the planets, while sometimes it is comparable with the Sun.

4. The head of a comet comprises the central and more brilliant portion near the nucleus, and a nebulous envelope called the coma. If by the word nucleus we were to understand a solid body comparable to the globes of the planets, and carrying a nebulosity like an enormous atmosphere, it would be a complete error. Examined with a strong telescope, the so-called nucleus loses all appearance of solidity, and resolves itself into a luminous fog more concentrated than its edges. Besides, certain decisive facts show the extreme fineness of cometary matter. Through the thickness of the comet, even through the nucleus itself, the feeblest stars remain visible and shine as if nothing intervened. But faced with this fact we must immediately reject any idea of solid or liquid matter. The lightest fog, and the most delicate smoke are coarse in comparison with them,

since at the thickness of a few hundred metres they form a screen which is impenetrable by starlight, while the cometary matter comprised within a thickness of over 1,000 miles allows the feeblest rays to pass. Can we, then, suppose it to consist of a gaseous transparent substance analogous to our atmosphere? No. Every gas, and air in particular, deviates the rays of light which traverse it, and makes them, in fact, what we call refracted. Nothing of the kind occurs as regards the ray from a star passing through a comet, even the centre of the nucleus. The ray is not deviated. It pursues its direction in a straight line as if it had encountered nothing on the way. What, then, is the nature of this strange cometary matter, which is neither solid nor gaseous? We are completely in ignorance. All that we can say is that matter is rarefied to a point unapproached by any terrestrial substance.[1]

5. There is another way of judging the feeble mass of comets. The attraction of matter for matter produces perturbations in the movements of heavenly bodies which are the stronger the greater the mass of the body producing the perturbations, and the smaller the mass of the perturbed body. The Earth, to give only one example, being heavy attracts the small bodies in the swarms of meteorites to the extent of drawing them to its atmosphere, or even on to its surface; but no asteroid can turn the Earth from its path. The Sun, the planets, the satellites, and the comets all obey this law of the strongest. We can, therefore, obtain some notion of the mass of the comets by observing the

[1] Comets are now believed to consist of swarms of small meteorites spaced fairly widely apart, while their tails are supposed to consist of a finely divided dust propelled by the light of the Sun.—Tr.

perturbations produced by a comet on the neighbouring planets, and the perturbations which the planet produces on them. In 1770 a comet appeared called Lexell's comet, which had not been observed before. In its course it came near the Earth, to within about six times the distance of the Moon. Very rarely has a comet come so close to us. What was the result of the struggle of attraction between our Globe and the other body which passed in our neighbourhood? The Earth did not seem to notice the presence of its visitor, but continued to rotate on its axis and revolve round the Sun as if nothing had happened. Its speed and its direction did not indicate the slightest change. It was very different for the comet. Retarded in its journey by the attraction of its powerful neighbour, it lost two days on its way. Finally it left our neighbourhood and made straight for the system of Jupiter. There it fell into great danger. It penetrated among the four moons of that planet, and traversed their orbits from end to end. What would happen to these feeble satellites under the attraction of the star? Would they not be all disturbed? Would not one or other of them desert Jupiter to be taken away by the comet? With such possibilities, astronomers never left their telescopes. The world of Jupiter would tell us what could threaten our world at some time or other. The result falsified all apprehensions. The comet passed without producing the slightest effect. None of the four moons was disturbed in its orbit, nor accelerated, nor retarded. As they circulated before the coming of the comet, so also did they circulate afterwards. One might have thought that nothing extraordinary had happened in that corner of the Universe. The comet, on the other hand, attracted here and there by the satellites

and Jupiter, abandoned its course, started on a new orbit, and thus it was lost in the depths of space. It has never been seen since. Under an enormous volume the comets, therefore, have a mass which is insufficient to produce the slightest perturbation on the bodies of the planet, or even on their satellites.

6. For a long time the comets struck terror among populations by their unexpected appearances and strange forms. People saw in them the precursors of pestilences, famine, and war. Common sense, that great faculty which consists in seeing things as they are, has, with the aid of science, made an end of these foolish terrors and superstitions. The sublime mechanism of the heavenly bodies takes no account of the miseries of man. A star does not cease to shine because a king dies, nor does a comet trail its rays in our sky in order to announce a war, the fruit of our own stupidity. On that we all agree to-day. But there arises another cause for anxiety which seems at first sight reasonable. Comets move in every imaginable direction, and it might be supposed that one of them would, some time or other, hit the Earth. In this case, would not the shock of the two heavenly bodies, each moving with prodigious speed, be fatal ? We must admit that if a comet of a mass comparable to that of the Earth were to hit us in its path, all would be lost in the seas and the continents under the influence of that shock. Fortunately such a catastrophe requires two conditions which never seem likely to be realised : the condition of mass and a condition of encounter. Let us first examine the probabilities of an encounter.

Imagine some grains of dust floating at random in the immensity of the air, and blown by the wind in every

direction. Is it reasonable to suppose that all of these grains will, sooner or later, collide? No. The extreme volume of the atmosphere does not give to this event anything but the very slightest probability. Now, as regards the space in which they move, what are the Earth and the comets but grains of dust? It would be foolish to consider their possible encounter.

The probability becomes greater if we were to suppose that the comet simply passed near the Earth. Geometry can tell us what would then happen. A comet with a mass equal to that of our Globe, which would pass between us and the Moon (a thing that has never yet happened), at the small distance of 37,000 miles, would somewhat retard the Earth in its orbit, and would bring the length of the year up to 367 days, 16 hours, and 5 minutes. The visit of the heavenly body would not, as you can see, be very terrible. We should escape with a small emendation of our calendar.

7. And yet we have given to the comet an exaggerated mass equal to that of the Earth. We know, on the other hand, that comets have very small masses, insufficient to cause the slightest alteration on the paths of planets and satellites. We know that their matter is rarefied to an extent that we cannot compare it to the slightest mist, or the finest gas. If, possibly, such a thing should happen, and an encounter actually take place, the feebleness of the mass of the comet would annul the results of the collision. We might traverse the comet without even perceiving it. The enormous nebulosity would offer no more resistance to the Earth than would a spider's web to a stone thrown from a sling.

But again, our sense of anxiety being ingenious in

raising objections, it has been urged that even though cometary matter is too subtle to be an obstacle to the Earth, could it not at least mingle with the atmosphere and make the latter unfit for respiration? Are we certain that a comet by brushing us with its tail might not introduce fatal substances into our atmosphere, and is it quite certain that all comets have transparent nuclei of a nebulous nature? Some comets have been too brilliant even in full daylight not to suggest the existence of more compact nuclei, which may be solid or even incandescent. Would the shock of those furnaces be without danger? To all these questions science gives no answer, since the study of comets is not sufficiently advanced. But from a more general point of view it answers as follows: On account of the immensity of celestial space, an encounter between the Earth and a comet is so unlikely that it is useless to discuss it. Have courage, children, if ever you hear these predictions of a visionary announcing the pending shock of a comet. The heavens are great. The Earth and the comet will find ample space for their orbits without collision. Besides, what do you fear? The laws of God are guiding them.

8. Instead of rushing along in a straight line by virtue of their original impulse, all the comets move in curved orbits under the Sun's attraction. They circulate round it like planets. But sometimes the orbit is indefinitely lengthened out in two branches which never meet, while at other times it forms a circuit returning upon itself. Those comets whose orbits do not return appear for a moment in the neighbourhood of the Sun, and then move away never to return. Perhaps they traverse immense distances in order to revolve round other suns which

they meet in their path. Those which follow closed orbits are invisible when the distance is too great, but eventually they reappear in our sky at periods whose duration depend upon the size of their orbits. These are called periodic comets. It is assumed that some of them take hundreds, or even thousands, of years to complete their orbits, the summits of which nearly touch the Sun, while the other extremes lie in the farthest limits of its domain. Astronomy does not yet possess sufficient data to calculate their path and predict their return. A small number of others have lent themselves better to calculation owing to their more frequent reappearances. To-day the astronomer can announce their arrival and predict the point in the sky where they can be seen. The chief of these comets are Halley's comet, which returns every 75 years; and Encke's comet, whose revolution is completed in 3½ years.

The English astronomer, Halley, the contemporary and friend of Newton, was the first to suspect the periodicity of comets. A comet appeared in 1682. Halley carefully studied its path, then comparing his observations with those of his predecessors, he believed he recognised in the comet of 1682 the comet which had appeared in 1607 and 1531. In all three cases the path described had been nearly the same. Therefore the three comets must be one, seen at intervals of 75 to 76 years. Seized with this important idea, Halley did not hesitate to predict the return of the comet 36 years later, which would be at the end of 1758, or the commencement of 1759. The illustrious astronomer did not live long enough to see the brilliant confirmation of his theories. Finding it impossible to determine exactly the perturbations which the comet might suffer from the planets,

Halley observed a wise reticence. But a French arithmetician, Clairaut, in 1758 cleared up the difficult problem and announced the passage of the comet for the middle of April 1759, with a margin of one month earlier or later. The comet was to have occupied 618 more days than in its previous revolution; a hundred days being due to Saturn and 518 to the action of Jupiter. The result confirmed these learned deductions. The comet reappeared within the limits assigned on 12th March, 1759.

Since that time, astronomers have taken into account the planet Uranus, which was unknown to Clairaut, and the action of the Earth, and have thus arrived at a greater precision. The next return, that of 1835, took place at the epoch predicted with an error of only 3 days in a period of 76 years. This marvellous agreement between fact and the predictions of calculation is one of the finest confirmations of astronomical theory. A comet, still unknown, appears in our sky, shines there for a few days only, then it plunges into the unknown and remains invisible for long years. But Science follows it step by step, and in its mind it sees it progressing day by day in its immense orbit, and it predicts for years in advance the date and point of its reappearance.

9. In going back to periods of 76 years, and comparing the orbits followed, we find that Halley's comet was the same which spread terror over Europe in 1456. Its tail formed a curved sword and was regarded as a presage of the success of the Turks over Christianity. At more recent times, in 1832, the periodical comet called after Biela, the astronomer who first observed it, was also the inoffensive cause of foolish terrors. According to calculations, the comet was to have crossed the orbit of the Earth

the night of the 29th of October. Among those persons who were unfamiliar with astronomical law there was a great panic. What should become of us if by any chance the Earth found itself at the point in its orbit to be traversed by the comet? Should we all be broken to pieces by the shock? Should we be carried into the nebulous matter of the star? The terrible night passes very quietly. At the moment when the comet cut our orbit the Earth was at least 50 million miles from the point of intersection. Let us repeat it: the heavens are great, and planets and comets circulate at their ease, without a risk of collision.

In one of its subsequent reappearances, in 1846, Biela's comet offered to astronomers a unique fact in the annals of the skies. Instead of the expected comet, two were seen to come back, two comets smaller than the original and travelling side by side without touching. The original comet had been split in two in its voyage. What had happened? Had it encountered some asteroid and split in the encounter? (It had actually traversed the region of the small planets between Mars and Jupiter.) Or had its nebulous mass been torn in two by contrary attractions? These are simply conjectures. What is certain is that to-day the comet has resolved itself into small shooting stars.

Encke's comet is remarkable for the short period of its revolution, amounting to about 3½ years. It is called a short-period comet. Yet its orbit reaches from Mercury to Jupiter. In compensation for the imaginary terrors which comets have often produced, it must be acknowledged that Encke's comet renders a service to Astronomy. Owing to the perturbations which it experiences in the neighbourhood of Mercury, it has enabled us to calculate

the mass of the latter planet, which, having no satellite, did not lend itself to the usual method of determining planetary mass. The comet which ignorant people would consider a sign of calamity has been utilised to extend our knowledge of the heavens. A comet does not indicate plagues for the Earth, it serves to weigh the planets.

The total number of comets circulating in our solar system seems to be very considerable. Already astronomical catalogues have enumerated 800 without counting the crowd of others seen at different epochs for which no precise data are available. Every year sees new comets. Perhaps the number of comets circulating within the orbit of Neptune alone may be put at several millions.

TWENTY-THIRD LESSON

THE STARS

The fixed stars. Scintillation, 1.—Measuring the distance of the stars, 2.—The ray of light which changes while it travels, 3.—The star visible for a long time after its annihilation, 3.—The great sphere above which the stars commence, 4.—The Earth's orbit seen from the inferior limit of the stars, 4.—Our Sun reduced to a speck, to nothing, 4.—The Earth illuminated by the Pole Star alone, 4.—Stars as primitive sources of light, 4.—Impossibility of measuring the angular diameters of stars, 5.—Stars seen in the telescope, 5.—A sun which the Earth's orbit cannot compass, 6.—Dimensions of Sirius, 6.—The stars are suns like our own, 6.—Classification of the stars, 7.—List of stars of the first magnitude, 7.—Number of stars visible to the naked eye, and with the telescope, 8.—Probable motion of the stars, 9.—Speed of the so-called fixed stars, 9.—The solar system moving towards the constellation Hercules, 9.—The heavens of the future, 9.

1. THE stars constantly occupy the same positions with respect to each other in the celestial vault. That is why they are called "fixed stars." The planets, on the other hand, owing to their revolution round the Sun, wander in the sky and successively pass the various constellations. To this characteristic which we have already mentioned, we must add another, which enables us to distinguish to some extent a star from a planet without a special astronomical investigation. The light of the stars is endowed with rapid movements or tremblings, which are called twinkling or scintillation. Our atmosphere seems to be the cause. Scintillation is the more active the purer the air, the lower the temperature,

and the less the height of the star above the horizon. The planets hardly twinkle at all. Saturn and Jupiter shine without twinkling, whereas Mercury, Mars, and especially Venus have sometimes quite a sensible scintillation.

On several occasions we have without any further proof considered the stars as self-luminous globes, situated well beyond the last planet, and constituting suns like our own, but very far away. We may now give this proof. In the first place, let us consider that of distance. In order to find the distance of an inaccessible object, I may remind you once more that we must have a base, and must construct on that base a triangle of which we measure the two angles within our reach. The construction of a similar figure, or, better, calculation, gives us the required distance. One indispensable condition must be fulfilled, and that is that there must be a reasonable relation between the base and the length to be measured. We have seen already that in the case of the Moon, our nearest neighbour in space, we had to construct the geometrical figure on a considerable portion of the Earth's circumference. To measure the distance of the Sun, the terrestrial Globe was found to be too small, and the imaginary line from the Earth to our satellite had to be adapted as a base. What base shall we choose for the stars? There is one which I have already mentioned, and it is the greatest at our disposal. It is the diameter of the Earth's orbit. On that line, 186 million miles long, we may succeed in building our triangle. Let us make the attempt.

2. At a given epoch, when the Earth is in the point T of its orbit, for example (Fig. 74), we point a telescope of a theodolite towards the Sun S, and the other telescope towards a star situated in a direction TE. This first

observation furnishes the angle ETT′. Six months afterwards, when the Earth has brought us to T′ at the other end of its orbit, the Sun is again studied in order to find the direction TT′, and the star is now seen in the direction T′E′. This gives us the angle E′T′T. We now know the base TT′ amounts to 186 million miles, and we know the two angles adjoining that base. This enables us to construct a similar figure.

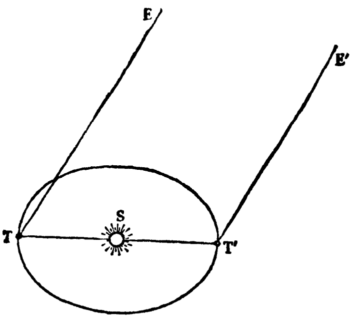


FIG. 74.

Now, in doing so, we find that for the immense majority of stars the two lines representing TE and T′E′ do not meet, however far they are produced. The base is still too small. A length of 186 million miles is insignificant when it has to support a triangle of which the star occupies the summit. Imagine now two straight lines which are to meet on the horizon, and are to start from the two ends of our hand. These two lines will, no doubt, eventually intersect, and will form a triangle based upon the hand. But that triangle is so pointed that our best instruments would show the two lines as parallel. In the same way, the two lines of sight, TE and T′E′, bending towards the same star from the ends of the base 186 million miles long, would meet indeed, but would meet at a distance so far away that they would appear parallel to any of our instruments of precision. To try to measure the distance of a star by means of the Earth's orbit is like trying to measure the size of a province by means of a base the size of our hand. In Geometry, as in everything

else, we must compare similar things—small things with small things, and very large things with very large things. The parallelism of two lines of sight drawn towards the same star at an interval of six months teaches us, by the impossibility of closing the triangle, that it is no use trying to compare distances which are incomparable with each other, these distances being a very "small" distance, viz. the immense diameter of the Earth's orbit, and a very great distance, viz. the distance of a star.

3. For some of the nearest stars astronomers have succeeded in calculating the triangle by taking minute precautions concerning accuracy. The result of their work is one of the most striking pieces of information concerning the heavens. Our mind is lost in the contemplation of stellar distances, so enormous are they when expressed in miles, or even in terms of the Earth's orbit. With these almost inconceivable distances, which can hardly be expressed in figures, a special measure is necessary, a measure as grand as the depths it is to sound. That measure is furnished by light. You will remember that, in order to reach us from the Sun, that is, to cover a distance of 93 million miles, a ray of light takes 8 months. Now astronomers tell us that, on the evidence presented by their gigantic triangles, light takes 3½ years to reach us from one of the nearest stars, Alpha in the Centaur Three and a half years, mind you, while light will cover 93 million miles in about half a quarter of an hour! But, listen again. Not all the stars are the same distance away. Most of them are, indeed, farther away. The star called the 61st of Cygnus takes 9 years and more to send us its rays. Vega in the Lyre takes 12 or 13; Sirius, 22; Arcturus, 26; the Pole Star, 31; and Capella, 72. A ray which now enters our eye has

been on its way for long years, although it travels with the enormous speed of 186,000 miles per second. It has been on its way for 31 years if it comes from Polaris, or for 72 years if it comes from Capella. Having grown old on its way, it does not bring us the present-day news of the star, but news of the past.

Beyond the stars which, like Capella, take a human lifetime to send us their rays, there are others much more numerous, yet whose light takes a hundred or even thousands of years to reach us. Calculations based on the diminution of the intensity of light at a distance give, for the probable distances of the farthest stars seen with the most powerful telescopes, a distance which it would take light 2,700 years to cross. Look at any one of the smaller stars which litter the sky. At the time when the star sent forth the light by which we see it now, none of us were living, and none of us will see the light it is sending out at the present moment, for its voyage takes more than a century. If we can suppose that a star were annihilated, it would still be seen for centuries, so long as the luminous beam on its way at the moment of the destruction of the star had not finished its journey. We should be deceived by an illusion occasioned by the travelling of light traversing those terrible distances, so that we should believe ourselves to be seeing a real object which would have gone out of existence some time ago.

4. Let us for the moment confine ourselves to the narrowest limits. Astronomers have succeeded in showing by incontestable proofs that the star nearest the Earth is at least 200,000 times as far away as the Sun. If, therefore, we described a sphere with a radius 200,000 times 93 million miles round the Earth at the centre, it is certain that no star would be within that

sphere.[1] It is beyond that sphere that the stellar regions commence. Let us imagine ourselves as transported to some point on the surface of that imaginary sphere, the lower limit of the stars. How would the Sun appear from there ? Or, rather, since the Sun would be a very small point, how would the Earth's orbit appear looked at from that distance ? Calculations show that the Earth's orbit would appear the size of a half-penny placed 1½ miles away ! That is the little circle in which the Earth moves at the rate of 67,000 miles an hour. A half-penny piece placed at a distance of 1½ miles from the eye would mask the Earth's orbit. As regards seeing the Earth itself when its orbit is so reduced, we could not hope to do any such thing. Could we hope to notice an atom of dust blown by a breeze above the clouds ? No, nothing can be seen of our Globe at the distance of the stars. All we can hope for is to see in the very middle of the circle which now represents the Earth's orbit for us a small bright object, a luminous point or spark. Now that spark is to us the glory of our world, the dispenser of life. It is the Sun. Let us repeat what has been proved by infallible reckoning ; at the distance of the nearest star, the Sun would only appear as a star of feeble brightness, such as the Pole Star.

This conclusion necessarily leads to another : stars shine with a brilliance inherent in them, not with light borrowed from the Sun. If the stars had received their light from the Sun, they would be illuminated by it much as the Earth itself is illuminated by a similar star at the same distance, such as the Pole Star. Now the whole of the starry sky is almost without effect on the darkness

[1] A smaller star, called Proxima Centauri, has recently been discovered at about half that distance.—Tr.

of the night. What would it be if the Pole Star shone alone? Seen closely, or from a distance, the Earth would remain completely dark under the rays of this star alone. In the same way, under the rays of our Sun, the stars would remain dark. But so far from being that, each one of them is a luminous point of greater or less brilliance. Some of them, like Sirius, Vega, Capella, and Arcturus, shine with a brilliant light. They must, therefore, be primary sources of light like the Sun itself.

5. Theoretically, the problem of the volume of the stars reduces itself to a measurement of their angular diameter once their distance is known. This would appear to be quite simple, as it only means the measurement of their apparent size. But consider this: seen from the Earth, the Sun has an angular diameter which can be easily measured. We have seen, in another chapter, that it is equal to 32 minutes and 6 seconds. Now what would be the angular diameter of the Sun seen from the nearest star? Calculations show that since the distance would be 200,000 times farther away than it is from us, its angular diameter would be reduced in the same proportion, and would become less than 1/100th of a second. None of our instruments for measuring angles can determine such a small quantity. One-hundredth of a second is beyond any of our theodolites. Therefore, in spite of its great size, the Sun would only appear as a point without dimensions at the distance of the stars. Conversely, the stars, though possibly as large as the Sun, would only be points to us. Yet we see them apparently of a certain size. This is due to the diffused irradiation with which they seem surrounded when seen with the naked eye. The employment of powerful telescopes gives them their appearance of sharp points by getting rid of

this irradiation. A star deprived of this illusory aureole becomes a true point. The more perfect and precise the instrument is the smaller is the starry point. It is a strange thing, if we do not take into account the enormous difference of distance, that the telescopes which enlarge the planets reduce the stars. Their power, paralysed by the disproportion of the distance, confines itself to depriving a star of its devious rays, and rendering it more distinct. The star thus becomes a simple point without dimensions. In general we may say that the angular diameter of stars is not appreciable with the means at the disposal of science.[1]

6. It is not that able observers have not applied instruments of great perfection to this class of research. Herschell, for instance, thought he had found an angular diameter of 2½ seconds for the star Capella. Now two seconds would be an angle under which the whole orbit of the Earth would be seen from the nearest stars. If Capella, therefore, really had the angular diameter which Herschell attributed to it, it would constitute a Sun which the whole orbit of the Earth would not encompass as a belt. It would constitute a sun over 20 million times larger than ours. Had the celebrated astronomer made a mistake? Had his instruments deceived him? Who can say that among the travellers of the skies there are not globes of such volume? According to the brilliance of its light, it is supposed that Sirius, the brightest star in our sky, is equivalent to a million of our suns.

If the imperfection of our instruments leaves too much

[1] A new method of measurement, based upon interference, has recently been advanced by Professor A. A. Michelsen, of Chicago, who has succeeded in measuring the diameter of some stars by this means.—Tr.

space for conjectures in questions regarding the volumes of stars, one truth at any rate stands out clearly. The stars are self-luminous globes. Their distance is such that, in order to reach us, light from the nearest star takes three or four years. On the other hand, the most elementary conclusions of Geometry teach us that our Sun, seen from a greater and greater distance, would fade away until it became similar to the Pole Star, if we could see if from the regions where the stars commence, and that it would vanish entirely if our point of observation were still farther away. Seen from the stars, the Sun is a star, while at a smaller distance it becomes the Sun. Since a greater or lesser distance converts the Sun into a star, or a star into a sun, just as it would convert a lamp into a spark or a spark into a lamp, we are irresistably led to the conclusion that the stars are suns comparable to our own: sources of light and heat, enormous bodies with planets and satellites, of dark worlds which our intellect may guess at, but which we shall never see.

7. Astronomers classify the stars into several orders depending on their brilliance. The brightest are called stars of the first magnitude, while those whose light is feebler are called stars of the second magnitude, and so on. You must not mistake this classification. It tells us nothing concerning the dimensions of stars, but only deals with their apparent brilliance. Sirius, for example, is of the first magnitude, and the Pole Star of the second. Does that mean that the Pole Star is less voluminous than Sirius? No, since its lesser brilliance can be the result of a lesser distance. If the size of a star and the intensity of its light tend to increase the brilliance of its appearance, its distance tends to reduce it. It may therefore easily happen that a star of the lowest order

of magnitude is really more important than another star classed as of the first magnitude. The smallest spark of a star at the limit of what the eye can see may be a giant in comparison with Sirius. The luminous dust which our eye dimly perceives in the depths of the heavens is always a dust of suns.

The first six orders of magnitude include the stars seen by the naked eye without a telescope. The subsequent orders comprise stars invisible without a telescope. Here I shall give a list of stars of the first magnitude visible in our skies, commencing with the most brilliant. The name of the star is accompanied by that of the constellation of which it forms a part.

Sirius ..	The Great Dog.	Aldebaran ..	The Bull.
Arcturus ..	The Drover.	Antares ..	The Scorpion.
Rigel ..	Orion.	Altair	The Eagle.
Capella ..	The Charioteer.	Spica	The Virgin.
Vega ..	The Lyre.	Fomalhaut ..	The Fish.
Procyon ..	The Little Dog.	Pollux	The Twins.
Betelgeuse .	Orion.	Regulus.. ..	The Lion.

In the southern hemisphere the following are also seen: Canopus, Alpha in Eridanus, Alpha and Beta of the Centaur, and Alpha and Beta of the Southern Cross. In all there are 20 stars of the first magnitude.[1]

8. The number increases rapidly in the lower orders of stars. Thus, there are 65 stars of the second magnitude, 190 of the third, 425 of the fourth, 1,100 of the fifth, and 3,200 of the sixth. The number of stars of all magnitudes visible to the naked eye is, therefore, about 5,000. Of these, about 1,000 never rise above our horizon, so that there remain 4,000 to fill up our sky. But since at a given moment only half of the sky is over our heads, the totality of stars seen at any one time is only about

[1] The stars of the same constellation are indicated by Greek letters.

2,000, though it may become 3,000 if the night is clear and visibility good. That is very little, since our first impression is that the number of luminous points in the skies is infinite. But in reality the wealth of the heavens does surpass our expectations. Let us take a telescope in order to count the stars of the last orders of magnitude. Then the numbers increase until they stagger our imagination. There are 13,000 stars of the seventh magnitude, 40,000 of the eighth, 142,000 of the ninth. The number of stars of the last orders is counted by millions. In that trail of faint light which circles the heavens and is called the Milky Way, Herschell estimated 18 million. Under the enlarging glasses of the telescopes, a small piece of the heavens no larger than the Moon becomes a hive of stars numbering by thousands. The total number of the stars from the first magnitude to the fourteenth is estimated at 43 million, and this is probably an under-estimate. Towards the fourteenth magnitude the power of our telescopes generally stops, but the stellar wealth of space does not stop there, since new regions of suns appear as our telescopes are improved, and they are beyond all counting. The universe of suns without end suspended like a casket before the throne of the Most High, where, then, are its limits ?

9. Observed superficially, the stars seem to preserve their relative positions in the vault of the heavens. Are they really immovable ? No. That repose is an illusion. In the Universe everything is in motion, not only the planets, but the suns themselves. If the stars seem fixed to us, it is because of the prodigious distance cancelling the fact of their displacement. In reality they are moving, and traversing space in mysterious orbits which defy our measures of time and space. It has taken all the precision of modern Astronomy to determine some

of their movements. The star called 61 Cygni is displaced every year by a small arc of 5 seconds, or the thickness of a thread placed some 100 feet from the eye. At the distance of the star itself, this thickness of thread attains gigantic proportions, amounting as it does to at least 100 million million miles. That is, therefore, the amount by which 61 Cygni moves in a year. In order not to lose ourselves in vast numbers, let us then limit ourselves to the space covered in one hour. In one hour, 61 Cygni covers 160,000 miles ; Arcturus, 190,000 ; Sirius, 90,000 ; and Capella, 94,000 miles. The Earth in its orbit covers 65.000 miles per hour. We can hardly form a conception of these furious speeds. But in spite of their apparent immobility, Sirius, Capella, and Arcturus are even faster than the Earth. These so-called fixed stars possess some of the greatest speeds with which matter is endowed.

All these stars, in various degrees, have, therefore, a movement of translation in various directions. Our own star, the Sun, forms no exception. Accompanied by its planets, it advances towards the constellation Hercules at the rate of 18,000 miles an hour. We do not know what power draws it towards that region of the sky. Does it revolve round an unknown star incomparably greater, and of which it would be a modest satellite ? We do not know. Stellar displacements, though hidden to our eyes by the enormous distances at which they take place, nevertheless accumulate with the centuries. A day will come when the constellations will have taken new shapes. But since human chronology is not the chronology of the stars, these transformations are so distant that there will be no people on the Earth to gaze at the new heavens.

TWENTY-FOURTH LESSON

THE STARS (*Concluded*)

Multiple stars, 1.—Revolution of the satellites of the suns, 1.—Coloration of multiple stars, 2.—Many-coloured daylight, 2.—Colour of simple stars, 2.—Periodic stars, 3.—Omicron of the Whale and Eta Argus, 3.—Variable stars. Disappearing suns, 3.—Temporary stars, 4.—New stars of 1572, 1604, etc., 4.—Reappearing stars, 4.—The starry heavens of our countries, 5.—Circumpolar constellations, 6.—Rules for finding the principal constellations, 7.—Constellations of the winter sky, 8.—Constellations of the summer sky, 9.

1. THE name " multiple stars " is given to stars occurring in two's, three's, four's, or more, forming part of the same system and revolving round each other. Double stars are the most frequent, 3,000 of them being known. Triple stars do not seem to be very numerous, and astronomical catalogues only enumerate 52. Groups of higher orders are even more rare. Castor or Alpha of the Twins is a double star, Alpha of Andromeda is triple, Epsilon of Lyra is quadruple, Theta of Orion is sixfold. Whatever their number, the companion suns which constitute a multiple star are always close enough to form a single bright point when seen with the naked eye. It takes the best telescopes and exceptional atmospheric conditions to see them separate. The star 61 Cygni, for instance, is a single star to the keenest sight. With a powerful telescope it can be split up into two stars of nearly equal brightness. We must not conclude that the

two are very close together, because it is so difficult to separate them. The two suns forming 61 Cygni are at least 4,200 million miles apart, that is, even more than the distance of Neptune from the Sun. The smaller of the two suns joined to the larger by the laws of gravitation revolves round it in an ellipse like the planets. It is sometimes seen above the principal Sun, then to the left of it, then below it, then to the right, and so on. In all multiple stars the same conditions obtain. The suns of smaller mass circulate like humble satellites round the predominating Sun, and describe elliptical orbits. The same force which governs our solar system and controls the circulatory movements of the planets, the Newtonian attraction, is exerted in the most remote regions of the Universe which our vision can attain. The fall of a stone to the ground explains to us the annual revolution of the Earth. It equally explains the revolution of a sun round another. The grains of dust raised by the wind and the suns on the confines of the visible Universe obey the same law.

A companion sun completes its orbit in a time which varies from one multiple star to another. The duration of revolution amounts to 36 years for the double star Zeta in Hercules, to 58 years in the star Xi of the Great Bear, to 78 years in Alpha of the Centaur, to 452 years in 61 Cygni, and to 1,200 years in Gamma of the Lion.

2. The suns composing a multiple star generally have different colours. While one is white, yellow, or red, others will be green or blue. Our Sun is white, meaning that it sends us white light. If it were to radiate blue light, that is, if it were blue, all objects on Earth would appear to us of a blue colour, as they would if we looked

at them through blue glasses. Daylight itself would be blue. It would be red with a red sun, and green with a green sun. Imagine at the centre of our solar system three or four suns instead of the one we have, and imagine one of them to be white, another blue, another red, and a fourth green. From the same hemisphere of the Earth these suns would be visible one by one, or two or three at a time, or all four together. For most of the time there would be no night, for hardly would one sun have set than another would rise. But even an uninterrupted day would have variety, for white daylight would be succeeded by red, green, or blue daylight. Thus there would be days with two suns, three suns, or four suns, an endless play of colours and heat effects by the mixture of the primordial rays in changing proportions. Well, these magnificent solar effects exist in reality on planets which have a multiple star instead of a sun.

3. Colours other than white are also found in isolated suns, but with less frequency. Thus Aldebaran, Arcturus, Antares, and Betelgeuse, which are simple stars, shine with a reddish light. Capella and Altair are yellow. Apart from some rare exceptions of this kind, all the other simple stars are white. There are some stars whose brightness increases and diminishes within more or less long periods. These are called periodic stars. Thus, Omicron in the Whale sometimes shines with the brightness of a first magnitude star. In October 1779 it was hardly inferior to Aldebaran. More often, it is of the second magnitude. After having shone with its greatest brightness for a fortnight, it fades away until it is invisible even in a telescope. This invisibility persists for five months. Then the star shines out again. It reappears and, growing in brightness every day, reaches its first

brightness, and then passes through the same period of about 332 days.

The star Eta in Argo is still more remarkable. That star is only visible in the southern hemisphere. At the commencement of last century it was classed as of the fourth magnitude. In 1837 Herschell, who observed it at the Cape of Good Hope, and who had found it to be of the second magnitude, saw it becoming brighter, and rapidly attaining a brightness nearly equal to that of Sirius. In a fortnight the transformation was complete. Then the star faded again, without, however, descending to its former magnitude. For a second time, and with the same rapidity, Eta in Argo came to rival Sirius in 1843, and its extraordinary brightness was maintained till 1850.

It is impossible to indicate the causes of these changes in brightness. Perhaps the so-called periodic stars have dark spots like our Sun, but of greater extent, and these reduce the brightness of their disk when they are turned towards us. Perhaps great opaque satellites corresponding to our planets intercept our view in their revolution, and produce true eclipses of those far-off suns.

Some stars undergo slow variations of colour or brightness without a periodic return to their original state. These are called variable stars. Some of them fade in the course of centuries, while others change in brightness as if their fires were liable to fail or to heat up. Others, while preserving the same order of magnitude, change their colour. In ancient days Sirius was a fiery red, while to-day it is a brilliant white. There are also rare cases of stars which have disappeared without a trace. This is a great question, as yet full of obscurity. Some suns fade away, others revive; some die and become

extinct. Will ours always keep its heat? Will the Earth, after losing its population, roll about in the dark round a dead sun?

4. On the other hand, new suns crop up. These stars, which are called temporary stars, appear suddenly in the sky, shine for a time, and are then extinguished. That was the case with the new star of 1572. Tycho-Brahe tells us that he was so surprised to see a star shining with exceptional brightness which had suddenly appeared in the constellation of Cassiopeia, that he hardly could believe his eyes. In the immutable skies a new sun had been lighted. The new star resembled the others in everything, but it twinkled more than the stars of first magnitude. Its brilliance surpassed that of Sirius. With good eyesight it could be distinguished in full daylight. Several times on a dark night it was visible through a cloud curtain, while all the other stars were veiled. It always kept its position in the sky just like the other stars. Two or three weeks afterwards its brightness began to diminish, and in March 1574 the star was extinguished after having shone for seventeen months.

We may also quote, among the most remarkable cases, the temporary star of 1604, observed by Kepler in the constellation of the Snake Bearer. From the very first days those who had seen the new star of 1572 found that this one was brighter than the former. Fifteen months afterwards it had totally disappeared after a gradual extinction. In 1670 a Nova or new star appeared near the Swan. This star was peculiar in that it appeared to be extinguished and to revive several times before disappearing entirely. To give a very recent example, we might add a little red star that appeared in 1848 in

the constellation of the Snake Bearer. This star disappeared in the course of a year.

Are the temporary stars absolutely new stars which are soon destroyed, like failures of creation? Or, are they the seat of some conflagration which makes them luminous and visible after having been invisible? Is some immense furnace, electrical or otherwise, suddenly lit on their surface only to go out sooner or later, or light up again? Matter is not destroyed, it is transformed until it pleases the Creator to throw it back into the nothing from which He brought it forth. The play of creations and of destructions is only an appearance, a tendency towards new forms. A sun is not annihilated simply because it ceases to be luminous. A phase of obscurity may be succeeded by new phases of brightness, by the renewed action of the forces which made it luminous in the first place.

5. After this rapid survey of the principal facts of the stellar universe, we must say a few words about the means of finding our way in the multitude of stars. You know that the groups of stars are arbitrarily called constellations, and are named after most various objects, instruments, animals, and personages, etc. You already know the Great Bear and the Little Bear. If your memory is at fault, read the chapter again which deals with these constellations, for they will serve for finding the others.

In a given place of observation, the curvature of the Earth hides from us a portion of the sky for ever. We should have to travel beyond the equator in order to explore the whole sky. I have sufficiently emphasised this point in another lesson, so that I need not return to it here. Only a portion of the starry heavens, therefore,

passes over our horizon, and half that portion is a day sky, while the other half is a night sky. It would seem, therefore, that half the constellations corresponding to our horizon must always remain invisible, being veiled by the daylight illumination. This would be the case, as I have said before, if the Earth remained always in the same place, and simply turned on its axis. But owing to our translation round the Sun, all those stars which rise above our horizon gradually pass into the night sky, and therefore become visible sooner or later. Let us consider this point a little more closely.

The solar day is four months longer than the sidereal day. A star which passes our meridian at the same time as the sun to-day, will pass it four minutes earlier to-morrow, eight minutes earlier the day after to-morrow, and so on. Thus, by the accumulation of successive advances, it will appear in our sky at night, and will thus be visible, although at first invisible. The aspect of the celestial vault is, therefore, different at different times of the year. We shall examine its principal features in winter and in summer, but let us first consider the circumpolar constellations.

6. The starry heavens appear to revolve in one piece round the axis of the Earth, which, prolonged ideally, meets the Pole Star. Each star describes a circle—to speak according to appearances—and this circle is greater or smaller according to its distance from the pole round which it revolves. But in the case of the stars near the pole the circle described is entirely above the horizon on account of the elevation of the polar axis, while other stars situated towards the celestial equator describe circles which plunge sometimes below the horizon. The former stars never rise and never set. Situated con-

stantly in the visible part of the sky, they always appear when the Sun sets, and are never hidden by the curvature of the Earth. The constellations formed by these stars are called the " circumpolar " constellations. The other stars, on the contrary, rise and set, that is, they appear on the eastern horizon, mount up in the sky, and set on the western horizon. The circumpolar constellations are visible every night at any time of the year. But in turning round the axis they may be found to the right or to the left, or above or below the pole according to the hour of observation. The Great Bear, the Little Bear, Cassiopeia, and Perseus are among these constellations.

I may remind you that the Great Bear is composed of seven principal stars, of which six are nearly equal in brilliance and of the second magnitude. Four of them are arranged in a long irregular square, while the remaining three start out from one of the angles and form a curved tail. On joining the two extreme stars of the square and producing the line joining them, the Pole Star is reached, a star of the second magnitude terminating the tail of the Little Bear. These two extreme stars are, therefore, called the " pointers."

The Little Bear is a constellation much smaller than the Great Bear, but is also formed by seven stars arranged very much like those of the Great Bear, but in a reversed order. Of those seven stars only three have any brilliance, the Pole Star and the two last stars of the square. The four others are only just visible.

7. That being so, let us imagine ourselves to be looking at the sky towards the end of December about 9 or 10 o'clock at night. The night is clear, and our point of observation enables us to see the whole of the starry

vault. Let us face northwards. The Great Bear is to the right of the pole, a little below it, with its tail pointing downward. Somewhat later in the night we can see it drawn upwards by the rotation of the sky until it reaches a position just to the right of the Pole Star. Still later, it would be above the pole, but that would be towards daybreak. On the other side of the square of the Great Bear, passing through the Pole Star, and therefore on our left, we should find near the Milky Way a beautiful constellation formed by six or seven principal stars in the shape of the letter **W**, or of an inverted chair. That constellation is Cassiopeia. It is always opposite the Great Bear with respect to the pole, being to the left of the Pole Star when the Great Bear is to the right, and above when the Great Bear is below, etc.

Two diagonals can be drawn across the square of the Great Bear; one of these passes into the tail, and the other does not. If the latter is drawn and is prolonged into the neighbourhood of Cassiopeia, it cuts across Perseus, a constellation of feeble brightness, which is, however, distinguished by the presence of Algol. That is a periodic star which in about 3½ hours passes from the second magnitude to the fourth magnitude, and returns to the second magnitude within the same period.

Near Perseus, high up in the sky, is a beautiful yellow star of the first magnitude called Capella, in the constellation of the Charioteer. The Charioteer itself is a great irregular pentagon. Capella is easily found by prolonging the side of the Great Bear nearest the pole in a direction opposite the pole. Capella is also one of the circumpolar stars.

8. Now turn southwards, and you will see the most beautiful constellations of the year. First of these is

Orion, a great irregular quadrilateral, in the centre of which there are three stars of equal brightness in a line close together. These three stars form the belt of the hunter Orion, who, with club in hand, kills the celestial Bull. The three stars are sometimes called the three kings, or the three magicians. Two of the stars situated at the four angles of the quadrilateral of Orion are of the first magnitude. The star at the top is Betelgeuse, and is of a reddish tinge. It forms the right shoulder of Orion. The principal star below is Rigel. It is white, and represents the left foot of the hunter. The line joining the three stars of the belt prolonged towards the south-east meets the brightest star in the sky, Sirius, in the constellation of the Greater Dog. To the east of the quadrilateral of Orion, at about the level of Betelgeuse, is another star of the first magnitude, Procyon, in the Lesser Dog. Sirius, Betelgeuse, and Procyon form an equilateral triangle traversed by the Milky Way. Now let us produce the line of the three kings in a direction opposite to Sirius. It encounters a red star of the first magnitude, that is, Aldebaran, the eye of the Bull. It terminates one of the branches of a sort of **V**, composed of five stars forming the head of the Bull. Beyond Aldebaran, and still in the direction of the line of the three kings, are the Pleiades, a group of six or seven smaller stars very close together and which require good eyesight to separate them. Aldebaran itself is in the middle of another group called the Hyades. The diagonal drawn through the square of the Great Bear to the corner where the tail begins, passes through Sirius at the other end of the sky. At half-way it traverses the twins, consisting of two bright stars, Pollux of the first magnitude and Castor of the second magnitude. These two stars are

above Procyon, nearly in the prolongation of the diagonal passing from Rigel to Betelgeuse.

9. Now let us take an evening at the end of June. The winter stars have disappeared; Sirius, Procyon, Rigel, Aldebaran are no longer visible, since they pass over our heads in the daytime. Other stars have succeeded them. The Great Bear is to the left of the Pole Star, and its tail is turned upwards. Cassiopeia is on the right, with the back of the chair lying horizontally. Bent like an index finger, the tail of the Great Bear shows us in the west, in the direction of its curve produced, a red star of first magnitude, Arcturus, in the constellation of the Drover. After passing Arcturus on continuing the curve of the tail of the Great Bear as if to complete the circle, we find Spica, another star of the first magnitude. This star belongs to the Virgin. Still in the west, but going northwards, we see Regulus, or the Heart of the Lion. The line of the pointers produced in a direction opposite the Pole Star meets this latter constellation, recognisable by its six stars raised in the shape of a sickle. The brightest star, Regulus, of the first magnitude, occupies the very end of the handle of the sickle. Nearly at the top of the sky, and to the east of Arcturus, there are seven stars arranged in a semicircle which are not, however, very brilliant. They form the northern crown, and one of them, of the second magnitude, is called the Pearl. On a line with Arcturus and the Pearl, and at double the distance, there is a very bright star of the first magnitude near the Milky Way. This is Vega in the Lyre. Four more small stars arranged in a regular rectangle are just below it. In 12,000 years Vega will be the Pole Star. The straight line from the Pearl to Vega meets the constellation of Hercules half-

way ; there is nothing very striking about that constellation. We need only remember that the Sun with its planets is making for that region of the sky at the rate of five miles a second. To the left of the Lyre, and in the middle of the Milky Way, which branches at this point, there are five stars arranged as a great cross with a longer branch horizontally and a shorter vertically. The star which occupies the head of the cross is nearly of the first magnitude, while the four others are of the third magnitude. That is the constellation of the Swan. Finally, a straight line drawn through the Pole Star and from the Swan encounters a little beyond the Milky Way three stars arranged in regular succession, the middle one of which is of the first magnitude. They form part of the constellation of the Eagle, and the principal star is called Altair.

TWENTY-FIFTH LESSON

THE NEBULÆ

The Milky Way, 1.—Shape and position of the Galaxy, 1.—Herschell's exploration of the Milky Way, 2.—Appearances due to a fog. The misty horizon, 3.—The grindstone made of suns. Explanation of the Milky Way, 4.—Sounding the firmament, 5.—Forms and dimensions of our nebulæ. Their distances, 9.—A voyage of a beam of light for a million years, 9.—Unresolvable nebulæ, 9.—The laboratory in which suns are made, 9.

1. WHO has not, on a fine starlight night, noticed a luminous streak, like a wisp of phosphorescent vapour, crossing the sky from end to end? Astronomers call it the Galaxy, or the Milky Way. We are told that in pagan times Juno one day was feeding Hercules. Some drops of the divine milk escaped from the lips of the nursling, spread over the celestial vault, and formed the Milky Way. Science has retained the name derived from the old legend. But, instead of the fabulous origin ascribed to it, it gives a much more majestic interpretation, as you will see.

To the naked eye the Milky Way looks like a light luminous mist arranged in very irregular bands. It surrounds the whole sky, dividing it into two nearly equal portions. In our hemisphere we see it in the winter, stretching across the constellations of Cassiopeia, Perseus, and Auriga; passing near Capella and Orion, cutting across the club of the latter and passing on towards Sirius. In summer it passes from Cassiopeia to the

Swan and the Eagle. At the Swan it divides into two branches, which re-unite in the southern sky near Alpha of the Centaur. Thus divided into two arcs over half its circumference, and single over the other half, it can be likened to a bracelet in which the metallic ring is doubled in order to insert a precious stone. The unarmed eye cannot discover anything more concerning the Galaxy. The telescope must tell us the rest.

2. If the telescope is pointed at any part of the Milky Way, a thousand brilliant points immediately appear where the eye only perceived a vague luminosity. The eye sees a swarm of stars, a heap of suns. Seen from a distance, the grains of sand on a beach make a uniform band. Seen close by, they resolve themselves into incalculable millions of separate grains. It is the same with the Milky Way. From afar, or with the naked eye, it is a wisp of milky luminosity, while in the eye of a telescope it is a prodigious accumulation of distinct stars, as if it were the beach of some celestial ocean containing suns instead of grains of sand. When Herschell studied this marvel of the sky, his telescope only covered a portion equivalent to a quarter of the Moon's disk; but in that restricted area the stars were counted up to 300, 400, 500, or even 600. Six hundred stars in a small corner of the Milky Way equal to a quarter of the Moon's disk, 2,400 in a space equivalent to the whole disk! We hardly see that number with the naked eye in the whole of the sky. In the field of the immovable telescope the stars renew themselves unceasingly, owing to their apparent revolution. Herschell endeavoured to count them. He estimated that in a quarter of an hour 116,000 stars had passed before his sight, and that the total number would reach 18 million.

3. Is the Milky Way what the telescope shows it to be: a ring of millions of suns, or is it the perspective of a uniform layer of suns in the middle of which we are situated ourselves? An example will explain what I mean.

Let us suppose that a fine mist lies on the ground round us to the height of about 10 yards. What shall we see in that mist, which extends indefinitely on each side, but is limited in the vertical sense? Over our heads our vision is practically unlimited on account of the low height of the mist. It only encounters a small number of particles of vapour, and the blue sky is hardly tarnished. In a horizontal direction, on the other hand, the eye sees an indefinite succession of mist particles in every direction, superimposed by a common perspective, and thus thickening round the spectator in a more or less opaque semicircle of fog. Thus a uniform layer of vapour, invisible along the line of its smallest dimensions, can trace a circular zone of cloud in the direction of its greatest dimensions. The circle of vapour which ordinarily traces out our horizon has indeed no other origin. The horizon is no more misty in the place where we stand, but it is there that the vapours uniformly spread over the soil are superimposed by perspective.

4. That being so, let us imagine with Herschell that millions and millions of suns nearly equidistant from each other are disposed in a flattened mass in a sort of lens of the shape of a grindstone, having a thickness which is small as compared with its vast dimensions in one plane. To use our former comparison, it will be a fog of suns limited in its thickness, but immense in length and width. Our sun is one of the stars of that layer, and we occupy a point somewhere in the middle of the grindstone.

Then everything is explained. If our gaze is directed along the thickness of the layer, it only meets a small number of stars, and the sky in that direction appears comparatively empty. If we look along the width of the layer, our gaze encounters so many stars that they seem to touch each other and join in a milky luminosity on account of their perspective. Thus the greatest dimensions of the grindstone of suns will be round us on the heavenly vault as a belt of accumulated stars, just as the greatest dimensions of a layer of fog are indicated by a circular zone of clouds. The Milky Way is, therefore, the perspective of the flattened layer of stars, of which we form a part, seen along its greatest dimensions. It is a sort of misty horizon of suns.

Let us sum up. All the stars which we see in the sky without a telescope, stars numbering at least 40 million, are arranged in a flat cluster in the middle of which our Sun may be found, a simple unit in the immense accumulation of its companion suns. To us who see it from the middle of its thickness, the stellar cluster is hardly seen in one direction, as it is too thin, while in the other direction it is revealed by a concentration due to perspective and called the Milky Way. The general form of the latter is that of a grindstone, but the division between the swarm in the centre shows us that half the Milky Way is divided into two layers. It can be compared with a disk of cardboard, one-half of which has been doubled and bent to display the two layers.

5. Herschell endeavoured to estimate the dimensions of this mass of suns. His method is so striking and simple that we must say a few words about it. If the stars of the Galaxy are nearly equally spaced—a very natural supposition—our eye must see more stars in any given

Q THE NEBULA OF ANDROMEDA.

[To face p. 332.

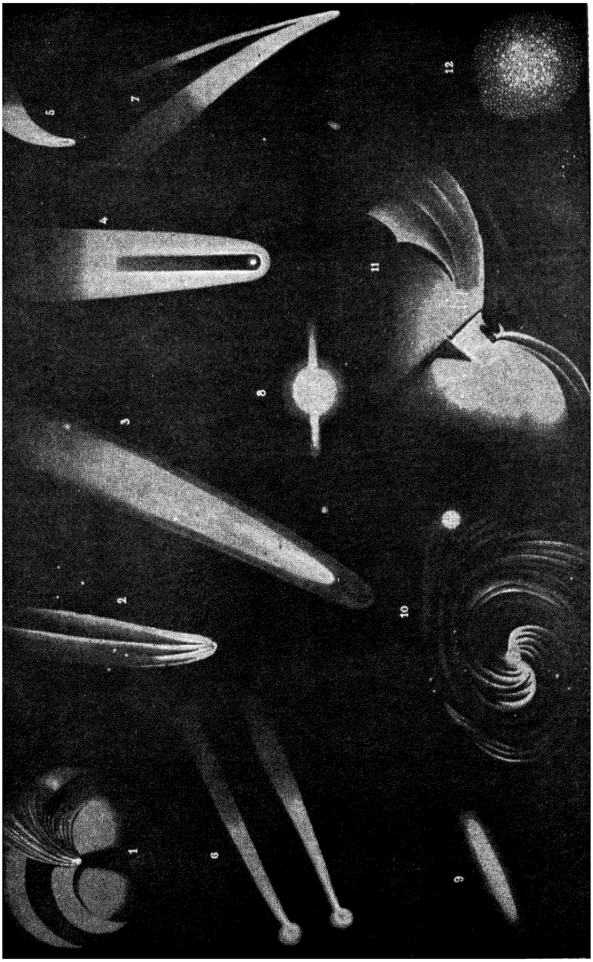
direction the deeper the layer. On this principle, Herschell sounded the firmament. His gauge or sounding lead was his telescope, which enabled him to plunge into the depths of our solar system. He found that in one direction of the sky the field of the telescope only contained one star, while in another direction it contained 10, and in a third direction 100, or 200, or 300, etc. From these numbers we may deduce the corresponding depth of the mass of stars in the various directions, and thus we may trace the configuration of the cluster.

6. Herschell found in this way that the galactic system is 100 times larger in the direction of its width than in the direction of its thickness, though, in spite of the penetrating power of his telescope, he was certain that he had not reached the end of that system in any direction. He also found on comparing the luminosities that the farther stars perceptible in the Milky Way were at least 500 times as far away as the nearest. Now, in order to reach us from the latter, light takes three or four years, and it must, therefore, take fifteen or twenty centuries to reach us from the outer limits of the Milky Way. It must take at least 3,000 or 4,000 years to traverse the whole system. And now, if you have any strength of imagination, try to form an idea of the mass of suns in which we are buried. A ray of light starts from the edge of the system. It devours space before it, and lightning is too slow to follow it. We can only follow it in thought. In the time it takes you to spell these words, in a single second, 186,000 miles, or seven or eight times the circumference of the Earth, have been covered. In the following second it covers another 186,000 miles, and so on, and so on, for light, once started, keeps its velocity. Years pass by, centuries, thousands

of years, and yet the ray has not reached its goal. It is only 4,000 years after it started that it reaches the other end of our system; and who knows, for the dimensions given by Herschell are below the truth according to his own view, who knows but that it may be 10,000 years as some say? It is not drops of milk from the lips of Hercules that can have filled these immensities.

7. The Milky Way traces around us a circular belt in the sky because we are placed in the very centre of the starry cluster. The Milky Way is, in fact, an effect of our central point of view; but if we were placed somewhere outside it, its aspect would be quite different. Let us suppose ourselves at some distance outside the starry grindstone. It would then appear to us as an immense disk of luminous points covering the whole sky. Let us imagine ourselves moving farther and farther away from it. The stellar disk would become smaller, and its luminous points would close up together until they formed a milky luminosity. Finally, when the distance had grown sufficiently, the tremendous mass of suns would only be a white nebulosity, the size of our hand. It has been calculated that at a distance 334 times its length it would be seen under an angle of 10 minutes, or like a crown-piece at a dozen yards. We are not really able to see our stellar system gathered up into such a small space by distance, yet our reason, guided by Geometry, enables us to form a true picture. It sees the immense cluster in which the suns are counted by millions and millions, lost in a small corner of space. It sees it like a small round object, whose uncertain light recalls the flickering light of phosphorus.

8. Now from the Earth we can see with a good tele-



R. COMETS AND NEBULÆ.

1. Head of the Comet of 1861.—2. Great Comet of 1881.—3. Great Comet of October 1882.—4. Coggia's Comet, 1874.—5. Comet of 1853.—6. Biéla's Comet, 1846.—7. Comet of 1861.—8. Verseau's Planetary Nebula.—9. Elliptic Nebula of Andromeda. 10. Nebula in the Hunting Dogs.—11. Orion Nebula.—12. Star Cluster in the Centaur.

[*To face p.* 334.

scope what our mind can see in imagining our stellar system at a distance. In many regions of the sky, the telescope shows us beyond our system of stars some luminous patches of feeble clouds of milky aspect, many of which are nebulous aggregations like our own, which are really clusters of suns. Over 4,000 of these have been found by astronomers, and more are being added as the penetrating power of telescopes advances. Very few of them can be seen with the naked eye, but the majority are too small and feeble to be seen in any but the best telescopes. With a small magnifying power they appear as tiny wisps of cloud with a soft luminosity. One feels afraid of breathing lest one might extinguish them.

But as the magnification is increased, the stupendous reality unfolds itself, for each of these luminous flecks which look so delicate turns out to be a cluster of stars. The nebula, which appeared homogeneous, is resolved into a swarm of small brilliant points or stars just as we have found in a portion of the Milky Way. It is impossible to estimate the number of these suns. Our own nebula, the system of the Milky Way, is therefore not the only one. There are, in the fields of the heavens, other heaps of stars in numbers which probably will never be counted, and separated from each other by great void spaces. The Universe becomes like an ocean whose shores are unknown, studded with immense archipelagoes of star clusters.

9. These celestial archipelagoes have all sorts of shapes. Some are globular and perfectly spherical, and some oval. Others branch out into wisps, curve round in crowns, or spread out in luminous lines which may be straight or wavy. Some resemble the nuclei of comets,

enveloped in their coma. Some of them group their stars in spiral whirls about a common centre looking like Catherine wheels. As regards their distance, little is known; but in order to appear at an angle of ten minutes our own nebula would have to be removed to a distance of 334 times its own diameter. Now we have seen that in order to traverse this diameter a ray of light would take at least 3,000 or 4,000 years, and possibly 10,000. Taking the smallest number, we get 334 times 3,000, or more than a million years, which light would require to reach us from a distance where our own nebula would be seen at an angle of 10 minutes. Some nebulæ have just that apparent size of 10 minutes, while others are smaller. These nebulæ are, therefore, so far away that light would take a million years to reach us from them.

Besides the nebulæ which the telescope has resolved into brilliant points or stars, and which therefore have been called resolvable nebulæ, astronomers also know others which resist the resolving power of their instruments, and remain milky patches of uniform illumination whatever the magnification employed. These are called unresolvable nebulæ. They do not take regular forms, but have the general aspect of clouds blown by a violent wind. They consist of diffused matter, having some analogy with the tails of comets. These heaps of finely divided substance seem to be celestial laboratories where new sums are being slowly evolved by the forces of attraction.

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